Essays on the Causal Relationship Between Short-Term and Long-Term Interest Rates

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Abstract

This thesis is about the causal relationship between interest rates. In chapter 1, with the help of time-series econometrics and by applying linear Granger causality tests based on the Toda-Yamamoto approach, the linear causality directions between the federal funds rate and five different interest rates during the last seven business cycles in the U.S. are investigated. We also examine the linear Granger causality directions between the overnight rate and five other interest rates during the last three business cycles in Canada.

In chapter 2, the Diks and Panchenko Granger causality test is applied to explore the nonlinear causality effects between the short-term and long-term interest rates. By combining nonlinear causality effects with the linear ones which are found in the first chapter, it is seen that during the related periods in the U.S. and Canada, the most common Granger causality direction between short-term and long-term interest rates is a bidirectional one. Moreover, our findings show that during recent periods, the federal funds rate and overnight rate Granger cause other interest rates significantly.

In chapter 3, the rolling window strategy is employed to detect the linear and nonlinear Granger causality relationship between the federal funds rate and the 10-year government bond rate, during different time horizons, investigating whether these causalities change with the passing of time. Our findings show that during different time horizons, there is a significant two-way Granger causality relationship between these interest rates.

Although we have a different interpretation of the existence of bidirectional causation between short-term and long-term interest rates, this conclusion provides some support to some post-Keynesian structuralists viewpoints like Pollin (2008). However, Pollin's claim indicating that with the passing of time the significant causality effects of the federal funds rate to the market rates becomes insignificant is not supported by the current thesis findings because our results demonstrate that these causality effects have not been diminishing over the most recent business cycles.

Sommaire

Cette thèse porte sur les liens de causalités entre les taux d'intérêt. Dans le premier chapitre nous analysons les directions du lien de causalité linéaire entre le taux des fonds fédéraux et cinq taux d'intérêt différents observés durant les sept derniers cycles économiques au États-Unis. Des séries chronologiques et des analyses de causalité linéaire de Granger basées sur la méthode de Toda-Yamamoto permettent de faire l'étude mentionnée ci-dessus. Nous analysons aussi les directions de causalité linéaire de Granger entre le taux du financement à un jour et cinq autres taux d'intérêt observés durant les trois derniers cycles économiques au Canada.

Le test de causalité de Granger proposé par Diks et Panchenko est utilisé dans le deuxième chapitre afin d'analyser les effets de causalité non-linéaire entre les taux d'intérêt à court terme et ceux à long terme. En incorporant les effets de causalité non-linéaire aux effets de causalité linéaire identifiés dans le premier chapitre, on remarque que durant les périodes communes aux États-Unis et au Canada, la direction de causalité de Granger entre les taux d'intérêt à court terme et ceux à long terme est surtout bidirectionnelle. De plus, les résultats indiquent qu'au cours des récentes périodes, les taux des fonds fédéraux et les taux de financement à un jour ont un effet Granger significatif sur les autres taux d'intérêt.

Dans le chapitre 3, une stratégie de période mobile est utilisée afin d'identifier la relation de causalité linéaire et non-linéaire de Granger entre le taux des fonds fédéraux et les obligations d'État à dix ans au cours de périodes de durée variées. On analyse aussi si ces causalités changent avec le temps. Nos résultats démontrent que durant les diverses périodes analysées, il y a une relation de causalité de Granger significative et bidirectionnelle entre ces taux d'intérêt.

Bien que nous ayons une interprétation différente de la présence de causalité bidirectionnelle entre les taux d'intérêt à court terme et ceux à long terme, les résultats supportent partiellement le point de vue de certains structuralistes post-keynésiens tels que Pollin (2008). Il faut toutefois mentionner que cette thèse ne supporte pas les résultats de Pollin qui stipulent qu'avec le temps les effets significatifs de causalité des tauxdes fonds fédéraux

deviennent négligeables. En effet, nos résultats démontrent que ces effets de causalité ne sont pas atténués durant la plupart des cycles économiques récents.

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to my dear parents,

Forough Hezarehei and Ali Rahimi

and my lovely sister,

Armaghan Rahimi

Table of Contents

General Introduction

There are several schools of thought in macroeconomics. In general, they can be divided into two groupings. The first grouping – the bigger one – is mainstream economics, also called orthodox economics or neoclassical economics. It contains new classical economics, new Keynesian economics, and their attempted synthesis (the new consensus). The second grouping is called heterodox economics, which includes in particular post-Keynesian economics.

There are important differences between the beliefs of orthodox and heterodox economists in the field of monetary economics. Orthodox economists presume that the money supply is exogenous and they believe that it is deposits that allow for credits; whereas post-Keynesian economists believe that money is endogenous. Post-Keynesians argue that causality goes from credits to deposits (Lavoie 1984). Also, unlike the mainstream, "*... for post-Keynesians, if credit rationing occurs, it is mainly because of a lack of confidence on the part of the banking or financial system, and not so much because of asymmetric information.*" (Lavoie 2011, p. 35-36)

Some mainstream authors believe that money is neutral; meaning changes in the money supply do not have long run effects on the real economy and, according to the quantity theory of money, it only causes a change in the general price level. Unlike neoclassical economists, post-Keynesians believe that money is not neutral. In addition, they argue for reverse causation: the growth in the money supply is caused by the growth in output and prices.

Based on the loanable funds theory, within the mainstream school, the interest rate equates the supply of and the demand for credits, which corresponds to real saving and investment. These factors are also known as thrift and productivity (Froyen 1996), and the obtained interest rate is called the natural rate of interest (Wicksell 1936), which also corresponds to full employment (Rousseas 1972). By contrast, in the post-Keynesian school, the base interest rate is set exogenously by the monetary authorities and this rate in normal times has a close relationship with other short-term interest rates. (Lavoie 2011)

These two streams have different interpretations of the liquidity preference theory. According to this theory, the demand for money is an inverse function of the interest rate. In the mainstream, money is just a medium for exchange and this feature of money creates a 'transaction demand' for it. It implies that by decreasing the interest rate, the cost of having money decreases and so agents keep more money for transaction. However, following Keynes (1936), post-Keynesian economists consider two more elements of the money demand function: 'precautionary demand' and 'speculative demand'. By adding these two elements to the money demand, they consider money not only as a medium of exchange but also as an asset (Ackley 1978). With the help of Keynes's liquidity preference and speculative demand, post-Keynesians also explain the difference and divergence between short-term and long-term interest rates. They believe that when short-term interest rates go to very low levels, people believe that this situation will not continue for a long time. They expect that in the future, interest rates will rise and the price of securities will decrease. Therefore, in order to escape from this future expected loss, they try to sell their securities and so the long-term interest rate would go up. This reaction makes long-term interest rate goes up and therefore and as a result, the term structure moves in a counter-cyclical manner (Seccareccia and Lavoie 2004).

The post-Keynesian school is itself divided into two streams; the so called horizontalists and the structuralists. Horizontalists believe that the money supply is a flat line at the interest rate which is set by the central bank. In other words, the central bank fully accommodates the demand for credit-money and it reacts to the demand for reserves with the infinite elastic reaction function without exerting any quantity constrain on the bank reserves (Fontana, 2003). This is the reason why in the literature this branch of post-Keynesians is also called accommodationists. Regarding the slope of the money supply function, structuralists address some critiques to the horizontalists. They believe that the central bank does not fully accommodate the demand for reserves in the monetary and banking system and that it imposes some quantity constraints on the reserves of banks (Pollin, 1991). Hence, the money supply function is not perfectly elastic and has a positive slope.

Another difference between these two streams concerns the liquidity preferences of the banks. Structuralists, unlike horizontalists that do not consider the liquidity preferences of the banks, believe that market short-term interest rates are obtained by adding a mark-up over the interest rate which is set by the central bank[1]. They believe that this *"... mark-up is a function of the lending risk and liquidity preference of banks. It depends on the expected default risk attached to the banks' loans and, more importantly, on the size and the composition of the banks' portfolios."* (Fontana, 2003, p. 303)

[1]- For more information see Deriet and Seccareccia (1996).

Finally, one of the most controversial debates between post-Keynesian horizontalists and structuralists is the causality relationship between short-term and long-term interest rates. Horizontalists hold that the short-term interest rate which is exogenously set by the central bank causes long-term interest rates; while structuralists believe that causality runs in the opposite direction, meaning from market-determined long-term interest rates to short-term interest rates (Lavoie 2011).

The topic of the current thesis is related to the last of the above-mentioned differences between horizontalist and structuralist economists: the causality relationship between short-term and long-term interest rates. To find the causality direction between these rates, in the first chapter, we will conduct the linear Granger causality tests. Then, non-linear tests will be applied in the second chapter. Eventually, a rolling-window strategy will be pursued in the third chapter.

Chapter 1

Linear Granger-causality between Short-term and Long-term Interest Rates during the Business Cycles

1.1 Introduction

Generally speaking, monetary policy actions can affect target economic variables by influencing interest rates. According to this belief, an expansionary monetary policy, by lowering both short-term and long-term interest rates, can stimulate investment and consumption, thus leading to a higher growth rate of the economy. By contrast, a contractionary monetary policy, by pushing up the interest rates, has the opposite effect on the economy.

The target overnight interest rate, also called the "*key interest rate" or the "key policy rate",* is a monetary instrument, the change of which is announced several specific times during a year. The Bank of Canada believes that *"Changes in the target for the overnight rate influence other interest rates, such as those for consumer loans and mortgages."* (Bank of Canada webpage[1]) The federal funds rate also acts as an instrument by which the Federal Reserve can influence the U.S. economy. Now, the questions that we are facing are as follows: Are these monetary instruments effective? In other words, can changes in federal funds rates or overnight rates affect the short-term and long-term interest rates significantly? If the answer is yes, do their significant effects change through time?

One of the most recent empirical works that attempts to answer these questions is Pollin (2008). In order to do so, he uses data of the last five full business cycles in the U.S. up to 2008, and with the help of linear Granger causality tests, examines the causal relationship between the federal funds rate and five market interest rates. In his paper, while the results of causality tests for the five business cycles show that there is a significant two-way causation

[1]- www.bankofcanada.ca/monetary-policy-introduction/key-interest-rate/

between the federal funds rate and the market rates, these causations become insignificant for the last business cycle. Therefore, Pollin, as a post-Keynesian structuralist, concludes that market interest rates, excluding the prime rate, are strongly determined by endogenous market financial operations while the power of the Federal Reserve to set and influence interest rates is limited.

In this thesis, with the help of time-series econometrics approaches and by applying Granger causality tests, we are also trying to answer the above-mentioned questions. To that end, the causality directions between the federal funds rate and five different interest rates during the last seven business cycles in the U.S. are investigated. We also examine the Granger causality directions between the overnight rate and five other interest rates during the last three business cycles in Canada. In the current chapter of this thesis, only linear Granger causality tests are applied. Then, we compare our findings to Pollin's results.

The outline for the rest of the chapter is as follows: In the next section, we review the relevant literature. Then, Granger-causality definitions are presented in section 3. In section 4, empirical methodology is explained. Afterwards, data, empirical studies and the results are described in section 5. Finally, a summary and the main conclusions are mentioned in section 6.

1.2 Literature Review

Neoclassical economists believe that in the case of arbitrage between different securities and no systematic error in the forecast of actual future yields, long-term interest rates would be an average of the current and the expected values of short-term interest rates for the related periods. This hypothesis comes from Irving Fisher (1930). According to his hypothesis, we should expect that long-term interest rates move with some lags in the same direction, but on a less fluctuant path, as that of short-term interest rates.

Robinson (1951) has several criticisms of the expectation hypothesis. She believes that in the case of no arbitrage, people cannot predict the future yields accurately. Moreover, some factors such as uncertainty, information costs and transaction costs could lead to a lack of relationship between long-term and short-term interest rates. Therefore, biased predictions would be inevitable.

In spite of some criticisms, the expectation hypothesis of the long-term interest rate is a consensus theory among neoclassical economists and many heterodox post-Keynesians. Moore (1988), as one of the post-Keynesian accommodationists, mentions that, *"long term rates are based on market participants' estimates of future short term rates."* (1988, p. 286).

Keynes believes that *"The short-term rate of interest is easily controlled by monetary authority ... But the long-term rate may be more recalcitrant when once it has fallen to a level which, on the basis of past experience and present experience of future monetary policy, is considered 'unsafe' by representative opinion."* (Keynes, 1936, p. 202-203)

Although all post-Keynesian economists agree that the supply of money is endogenous, their beliefs about the monetary authorities' ability to impose an interest rate on the whole financial system are not the same. Post-Keynesian horizontalists believe that *"... eventually, through persistence and arbitrage, the short-term rate of interest set by the central bank will become the standard for the whole of the financial system ... "* (Seccareccia and Lavoie 1998, p. 7). On the other hand, post-Keynesian structuralists' opinion is that *"... various market forces can disjoint the base rate of interest set by the central bank from other market rates (cf. Lavoie, 1996). In addition, some structuralists believe that market rates have an impact on the base rate set by the central bank, i.e., they have a feedback effect. "* (Seccareccia and Lavoie 1998, p. 7) They argue that, in line with the Cambridge equation[1], the rate of growth of the economy determines the rate of profit, while the economy-wide rate of profit determines the long-term rate of interest. This long-term rate of interest would be the ultimate determinant of short-term rates which can be set by the central banks. (Seccareccia and Lavoie 1998)

Pigou (1927), as a Cambridge economist, believes that although central banks can affect short-term interest rates, the long-term interest rate is out of control of monetary authorities. He says that this rate is derived from the capital market forces meaning from the demand and supply of real capital and so, it is the natural rate of interest. Therefore, other interest rates are closely related to the long-term interest rates. That means there is a one-way causality from the long-term rate of interest to the short-term ones.

Pollin (1991), by applying Granger-Sims causality tests, concludes that causality runs from the long-term rate of interest to the short-term rates of interest such as the federal funds rate and the

[1]- The Cambridge equation is $MV = PT$, where M is the demand for money, V is the velocity of money circulation, P is the price level and T is the real volume of transactions. (Oxford Reference: http://www.answers.com/topic/cambridge-equation)

discount rate. However, unlike short-term interest rates, long-term interest rates are not substantially controllable by the Federal Reserve through the federal funds markets. Although, Pollin agrees with some post-Keynesian horizontalist viewpoints, his test results are in contradiction with what horizontalists believe about the causal relation between the two interest rates. About Pollin's result, Seccareccia and Lavoie (1998, p. 8) say that *"These results would thus appear to give considerable credence to the belief that profit rates and long-term rates of interest are the ultimate determinants of the base rate of interest which central banks are compelled to set eventually."*

Moore (1991) and Palley (1991) try to interpret Pollin's results and provide some comments on his work. Moore, as a post-Keynesian horizontalist, explains that the current values of long-term interest rates are based on the present expectation of current and future short-term interest rates, which are administered by the monetary authorities. This is why a "Granger-causality" test can reveal a one-way causality from long-term bond rates to the short-term rates. He believes that *"… the fact that future values of the independent variable are associated statistically with present value of the dependent variable does not imply dependent variable causality, …"* (Moore 1991, p. 411) and based on Zellner (1979), he says that: *"As is well known in the case of behavior dependent on expectations of future events, Granger-causality must be read in reverse."* (Moore 1991, p. 411)

Finally, Palley (1991) asserts that although Pollin's findings seem to support the structuralist position, one should notice that these results are obtained because current long-term market rates contain expectations about future Fed's rates.

Atesoglu (2003-4), by using time-series econometrics and employing Johansen cointegration and vector error-correction modeling techniques, examines the relation between the federal funds rate and the prime rate for the two periods of 2/1987-1/1994 and 2/1994-5/2002. During the first sub-period, the Federal Reserve kept the target of federal funds rate confidential and it made it public during the second sub-period. This research concludes that there is a positive cointegration relation between the two interest rates, which is in support of the post-Keynesian monetary transmission mechanism. The results also show that for the first sample period, there is a two-way causality between these interest rates, which supports the post-Keynesian structuralist viewpoint. However, for the second sample period, there is only a one-way causality that runs from the federal funds rate to the prime rate, thus providing support to the views of post-Keynesian horizontalists. In his research, Atesoglu declares that in recent years, the Fed, through its monetary policy actions, can affect the prime rate faster and with more strength.

With the same method, Johansen cointegration and vector error-correction techniques, Atesoglu (2005) investigates the relationship between the federal funds rate and the AAA corporate bond yield for 2/1987-4/2004 and also between the federal funds rate and 30-year Treasury note yields for 2/1987–1/2002. His findings indicate that there is a long-run relationship between the federal funds rate and these two long-term interest rates. Moreover, in support of the post-Keynesian horizontalist viewpoint, he shows that there is a unidirectional Granger causality from the federal funds rate to the AAA corporate bond yield and also towards the 30-year Treasury note yield.

Payne (2006-7) applies the momentum threshold autoregressive model of Enders and Siklos (2001) and extends Atesoglu (2003-4). Enders–Siklos asymmetric cointegration procedure for the monthly data from 2/1987 to 6/2005 shows that the fixed mortgage rate and federal funds rate are cointegrated. Also, this paper finds that there is a one-way causality direction going from the federal funds rate towards the fixed mortgage rate which is in line with the perspective of horizontalists.

Pollin (2008) tries to measure the central bank power to determine interest rates exogenously. In order to do so, besides the federal funds rate, he uses five financial market interest rates: two short-term rates[1] and three long-term rates[2]. This is done over the last five full business cycles in the U.S. up to 2008. Pollin updates the econometrics techniques that were applied in his two previous papers. With the help of Granger causality tests, he examines the causality relationship between the federal funds rate and each of the above-mentioned market interest rates during the chosen periods. He also applies these tests to the data corresponding to the earliest and the most recent cycles to find whether the causality results change through time. While the results of causality tests for the full five business cycles show that there is a significant two-way causation between the federal funds rate and the market rates, these causations become insignificant for the last cycle. Therefore, Pollin, as a post-Keynesian structuralist, concludes that market interest rates, except the prime rate, are strongly determined by endogenous market financial operations. He also concludes that the extent to which market rates are controlled by the Federal Reserve is limited. As we can see, these conclusions are in contradiction with the post-Keynesian horizontalist perspective. Pollin (2008, p. 24) believes that *"The movement toward financial market deregulation since the 1970s has therefore meant a movement toward increased interest rate endogeneity. It*

[1]- The 6-month Treasury bond rate, and the bank prime rate

[2]- The 10-year Treasury bond rate, the 30-year mortgage rate, and the Baa corporate bond rate.

follows that effective regulatory policies to stabilize markets and control interest rates directly will increase the degree of interest rate exogeneity." (Pollin 2008, p. 24) Therefore, he suggests that in order to obtain stable financial markets and to increase the extent of interest rate exogeneity, regulatory policy should be applied.

Finally, a more recent study, that of Jansen (2013), uses quarterly data of short-term and long-term interest rates, from 1970 to 2004 for 12 countries, by estimating a rolling regression model and with the help of the ECM model tests the Granger causality between short-term and long-term interest rates. The results of this paper indicate that in the United States, Spain, Belgium and Switzerland, there is a unidirectional causality from short-term to long-term interest rates; while in the United Kingdom, the unidirectional causality is in the opposite direction. In other countries, the results do not show significant causality between short-term and long-term interest rates.

As we can see, among all of the aforementioned, only Atesoglu (2003-4 and 2005), Payne (2006-7), Pollin (2008) and Jansen (2013) apply Granger-causality tests in the context of non-stationary data. Therefore, the other papers that do not consider data non-stationarity have some problems and are unreliable. In the current paper, we will employ the Toda-Yamamoto procedure for conducting linear Granger-causality tests. This method avoids some of the problems related to other techniques.

1.3 Linear and Nonlinear Granger Causality Definitions

The aim of this study is to test the linear causality relationships between short-term and long-term interest rates by extending the method proposed by Clive Granger (1969). The concept of causality in social sciences is more difficult to apply than in natural science. *"For* *natural science, researchers can perform experiments where all other possible causes are kept fixed except for the sole factor under investigation."* (Lin 2008, p. 1) Unlike natural science, in social sciences, researchers cannot exert such condition because *"... different variables affect the same variable simultaneously ..."* (Lin 2008, p. 1) Despite these difficulties in finding causality effects in the social sciences, Granger (1969) suggests an applicable causality definition for economics based on forecasting.[1]

A simple intuitive definition of Granger causality is as follows:

Consider X_t and Y_t as two time series variables. X_t Granger causes Y_t if the previous values of X_t can help to improve the forecasting of variable Y_t statistically; if X_t cannot help to improve the prediction of Y_t, it will not Granger cause Y_t.

In other words, consider two strictly stationary time series X_t and Y_t. X_t Granger causes Y_t, if its current and previous values contain information, in addition to what is contained in the current and previous values of Y_t, that can significantly affect future values of Y_t.[2]

It is said $\{X_t\}$ Granger causes $\{Y_t\}$ if for $s \geq 1$:

$$(Y_{t+1}, \dots, Y_{t+s}) | (I_{X_t}, I_{Y_t}) \nsim (Y_{t+1}, \dots, Y_{t+s}) | (I_{Y_t}) \qquad (5)$$

I_{X_t} and I_{Y_t} contain the information of the past and current observations of X_t and Y_t respectively, and '$\sim$' denotes equivalence in distribution.[3]

[1]- Note that causality is a concept which is different from correlation. For more information see Aldrich (1995).

[2], 3- A similar definition of Granger causality can be found in Diks and Panchenko (2006).

The above statistical definition which is based on the total distribution of future Y_t is very general. According to Diks and Pancheko (2006, p. 1), *"Since this definition is general and does not involve any modelling assumptions, such as a linear autoregressive model, it is often referred to as general or, by a slight abuse of language, nonlinear Granger causality."* We will come back to the general definition of Granger causality with more details in the next chapter.

Part of the causality between two variables can be detected by applying a linear Granger causality test that is based on the first moments of X_t and Y_t distributions. In this traditional test, the statistically significant power of past values of X_t in predicting Y_t can be tested by the VAR model found bellow:

$$Y_t = \alpha_{10} + \alpha_{11} Y_{t-1} + \alpha_{12} Y_{t-2} + \cdots + \alpha_{1p} Y_{t-p} + \beta_{11} X_{t-1} + \beta_{12} X_{t-2} + \cdots + \beta_{1p} X_{t-p} + u_t$$

$$X_t = \alpha_{20} + \alpha_{21} X_{t-1} + \alpha_{22} X_{t-2} + \cdots + \alpha_{2p} X_{t-p} + \beta_{21} Y_{t-1} + \beta_{22} Y_{t-2} + \cdots + \beta_{2p} Y_{t-p} + v_t$$

If the null hypothesis $H_0: \beta_{11} = \beta_{12} = \cdots = \beta_{1p} = 0$ is statistically rejected in favour of $H_A: not\ H_0$, then X_t Granger causes Y_t. If H_0 cannot be rejected, then X_t does not Granger causes Y_t.

In the same way, if the null hypothesis $H_0: \beta_{21} = \beta_{22} = \cdots = \beta_{2p} = 0$ is rejected in favour of $H_A: not\ H_0$, then Y_t Granger causes X_t. Otherwise, it does not cause X_t.

In this chapter, we will use linear Granger causality tests.

1.4 Empirical Methodology

In order to conduct linear Granger causality tests in the case of non-stationary time series variables, this paper applies the Toda-Yamamoto (TY) procedure[1]. This approach is based on an augmented VAR (p + m) model in levels, where p is the lag length of the common VAR model and m is the maximum integration order of the series included in the model. The causality test is a Wald test in which the null hypothesis exerts zero restrictions on the first p parameters of the model and the test statistic follows an asymptotic Chi-square distribution with m degrees of freedom ($\chi^2(m)$). One should notice that when the data are non-stationary, the usual Wald test is not valid. This is because in this case, the test statistic under the null hypothesis does not have its usual asymptotic Chi-square (χ^2) distribution.

Both Johansen-Juselius[2] and Toda-Yamamoto (TY) procedures can be applied to conduct a linear Granger-causality test. However, the later has some advantages compared to the former. One of these advantages is that, unlike the Johansen-Juselius procedure, there is no need to perform some pre-tests for the cointegration of the series. Moreover, there is no variable in the related VAR model that appears in differenced form. Therefore, the Granger-causality test based on the TY method can be referred to as a long-run Granger-causality test.

Another benefit of the TY procedure is that since the test is based on a VAR in levels, not in differences, we do not have any information loss related to the differenced form data. (Doğrul and Soytas, 2010)

The Toda-Yamamoto approach will be explained briefly in the following section.

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[1]- Toda and Yamamoto (1995)

[2]- Johansen and Juselius (1990)

Toda-Yamamoto Approach to Granger Causality[1]

In this section, we are going to explain the Toda-Yamamoto general model. Assume we have the following random process:

$$x_t = \alpha_0 + \alpha_1 t + \cdots + \alpha_p t^p + \gamma_t \qquad (1)$$

that generates a n-vector time series $\{x_t\}_{t=-k+1}^{\infty}$ in which $\{\gamma_t\}$ is an integrated vector of order d that comes from the following vector autoregressive process:

$$\gamma_t = C_1\gamma_{t-1} + C_2\gamma_{t-2} + \ldots + C_k\gamma_{t-k} + u_t \qquad (2)$$

in which k is known and $\{u_t = (u_{1t}, \ldots, u_{nt})'\}$ is i.i.d of $N(0, \Sigma_u)$ such that $\Sigma_u > 0$ and $\mathbf{E}|u_{it}|^{2+\varepsilon} < \infty$ for some $\varepsilon > 0$.

From (1), we can derive the following equations:

$$\gamma_t = x_t - \alpha_0 - \alpha_1 t - \cdots - \alpha_p t^p \qquad (3)'$$

$$\gamma_{t-1} = x_{t-1} - \alpha_0 - \alpha_1(t-1) - \cdots - \alpha_p(t-1)^p$$

$$\gamma_{t-2} = x_{t-2} - \alpha_0 - \alpha_1(t-2) - \cdots - \alpha_p(t-2)^p$$

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$$\gamma_{t-k} = x_{t-k} - \alpha_0 - \alpha_1(t-k) - \cdots - \alpha_p(t-k)^p$$

By substituting the above equations into equation (2) we have:

[1]- This part has been taken from Toda and Yamamoto (1995).

$$x_t - \alpha_0 - \alpha_1 t - \cdots - \alpha_p t^p = C_1(x_{t-1} - \alpha_0 - \alpha_1(t-2) - \alpha_2(t-2)^2 \ldots - \alpha_p(t-2)^p)$$

$$+ C_2(x_{t-2} - \alpha_0 - \alpha_1(t-2) - \alpha_2(t-2)^2 \ldots - \alpha_p(t-2)^p)$$

$$+ \ldots$$

$$+ C_k(x_{t-k} - \alpha_0 - \alpha_1(t-k) - \alpha_2(t-k)^2 \ldots - \alpha_p(t-k)^p)$$

$$+ u_t \qquad (3)''$$

After some manipulations, x_t is obtained as:

$$x_t = \mathrm{w}_0 + \mathrm{w}_1 t + \cdots + \mathrm{w}_p t^p + C_1\gamma_{t-1} + C_2\gamma_{t-2} + \ldots + C_k\gamma_{t-k} + u_t \qquad (3)$$

where $\mathrm{w}_i (i = 0,1,\ldots,p)$ is a function of α_i $(i = 1,2,\ldots,p)$ and C_h $(h = 1,2,\ldots,k)$.

Now, consider the following hypothesis about the parameters of model (3)[1]:

$$H_0: C_{K+1} = C_{K+2} = \cdots = C_q = 0 \qquad (4)$$

where $t = 1,\ldots,T$ and $q \geq k + d$.

At the first stage, we impose the above restrictions on the parameter of equation (3) and then we estimate the VAR model by **OLS** technique. Therefore, we have:

$$x_t = \widehat{\mathrm{w}}_0 + \widehat{\mathrm{w}}_1 t + \cdots + \widehat{\mathrm{w}}_p t^p + \hat{C}_1 x_t + \cdots + \hat{C}_k x_{t-k} + \hat{C}_{k+1} x_{t-k-1} \ldots + \hat{C}_q x_{t-q} + \hat{u}_t \qquad (5)$$

[1]- In the general case, the null hypotheses can be writhen as follows:

H_0: $f(\vartheta) = 0$

where $\vartheta = \mathrm{vec}(\theta)$ and $\theta = (C_1,\ldots,C_k)$; and at the neighborhood of ϑ, $f(\cdot)$ is a twice continuopusly differentiable function such that $rank\left(F(\cdot)\right) = m$, where $F(\varphi) = \partial f(\varphi)/\partial\varphi'$.

Equation (5) can be written as the following format:

$$x_t = \widehat{\boldsymbol{\omega}}\tau_t + \widehat{\boldsymbol{\Theta}} y_t + \widehat{\boldsymbol{\delta}} z_t + \hat{u}_t \qquad (6)$$

where $\widehat{\boldsymbol{\omega}} = (\widehat{\omega}_0, \dots, \widehat{\omega}_p)$, $\tau_t = (1, t, \dots, t^p)'$, $y_t = (x'_{t-1}, \dots, x'_{t-k})'$, $z_t = (x'_{t-k-1}, \dots, x'_{t-q})'$, $\widehat{\boldsymbol{\Theta}} = (\hat{C}_1, \dots, \hat{C}_k)$ and $\widehat{\boldsymbol{\delta}} = (\hat{C}_{k+1}, \dots, \hat{C}_q)$.

Also, in the matrix format we have:

$$X' = \widehat{\boldsymbol{\omega}}\Tau' + \widehat{\boldsymbol{\Theta}} Y' + \widehat{\boldsymbol{\delta}} Z' + \widehat{U}' \qquad (7)$$

such that $X = (x_1, \dots, x_T)'$, $\Tau = (\tau_t, \dots, \tau_T)'$, $Y = (y_1, \dots, y_T)'$, $Z = (z_1, \dots, z_T)'$, $U = (u_1, \dots, u_T)'$ and $\widehat{\theta} = vec\,(\widehat{\boldsymbol{\Theta}})$.

Now, the standard Wald statistics can be derived by the following formula:

$$\boldsymbol{W} = f(\widehat{\theta})'[F(\widehat{\theta})\{\,\widehat{\Sigma}_u \otimes (Y'QY)^{-1}\}\,F(\widehat{\theta})']^{-1} f(\widehat{\theta}) \qquad (8)$$

Where $\widehat{\Sigma}_u = T^{-1}\widehat{U}'\widehat{U}$, $Q = Q_\tau - Q_\tau Z(Z'Q_\tau Z)^{-1}Z'Q_\tau$, $Q_\tau = I_T - \Tau(\Tau'\Tau)^{-1}\Tau'$ and I_T is a $T \times T$ identity matrix.

Under the null hypothesis (4) and if $q \geq k + d$, the asymptotical distribution of **W** would be the chi-square distribution with m degree of freedom. Therefore, in order to test the null hypothesis, *"All we need is to determine the maximal order of integration* d_{max} *lag (i.e.,* p[1] $= k + d_{max}$*). That is, we have to pay little attention to integration and cointegration properties of DGP*[2]*."* (Toda and Yamamoto 1995, p. 6)

[1]- In our notation, instead of p, we have q.

[2]- Data Generation Process

For more information and details, one can refer to the Toda and Yamamoto (1995) article.

1.5 Empirical Analysis

In this chapter, we investigate the linear Granger causal relationships between, on one hand the federal funds rate (FFR) or the overnight rate (ONR), and on the other hand five different interest rates, during the last seven business cycles in the U.S. and the last three business cycles in Canada respectively.

The Granger causality tests are applied to each business cycle separately because we want to know how the causality relationships change through time.[1]

Our five different interest rates in the U.S. are as follows: the prime rate (PR), the 6-month Treasury bill rate (6MTBR), the 10-year government bond rate (10YGBR), the 30-year mortgage rate (30YMR) and the Baa corporate bond rate (BAACR). Our interest rates in Canada are the prime rate (PR), the 6-month Treasury bill rate (6MTBR), the 10-year government bond rate (10YGBR), the long-term government bond rate (LTGBR), and the 5-year mortgage rate (5YMR).

1.5.1 Data

In this thesis, we use weekly data. In the case of the U.S., the data is based on the last seven business cycles, from December 1969 to May 2012, and is obtained from the Federal

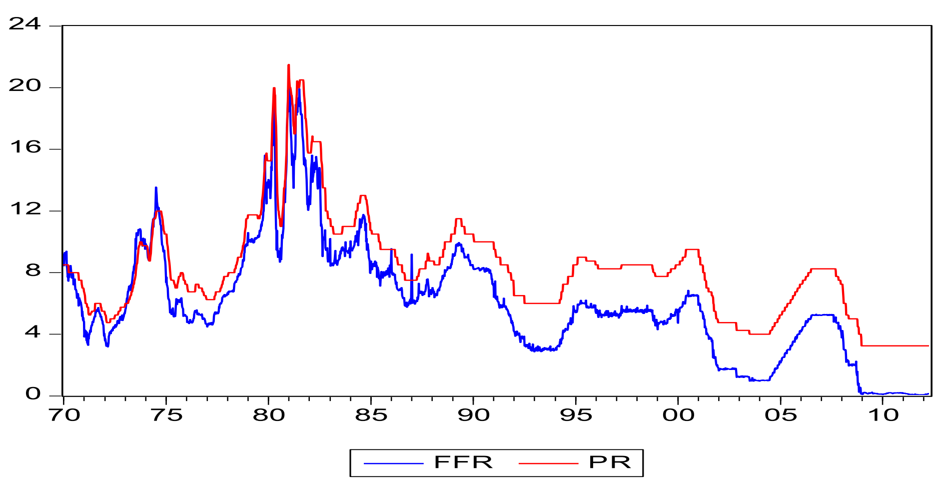
[1]- Because of the extreme number of observations problem, the results of applying Granger causality tests for the whole sample (December 1969 to May 2012) always show that there is a bidirectional causality between two related variables. Zhang, Lai and Wang (2009) also pointed to the extreme number of observations problem.

Reserve Bank of St. Louis database.[1]

In the case of Canada, weekly data are related to the last three business cycles, from June 1981 to November 2012 and are obtained from the Bank of Canada database. The information about the duration of different business cycles in the U.S. and Canada has been taken from the National Bureau of Economic Research[2] and the C.D. HOWE Institute[3] respectively.

The behaviours of different interest rates in relation to FFR and ONR in the U.S. and Canada, respectively, are illustrated in Figures (1-1) to (1-10). As we can see, two short-term interest rates, PR and 6MTB have a very close relationship with the federal funds rate and overnight rate. However, the relationship between the federal funds rate and overnight rate with three long-term interest rates, i.e., 10YGBR, 30YMR and BAACR in the U.S., and 10YGBR, LTGBR and 5YMR in Canada, are much weaker.

Figure (1-1) - Federal Funds Rate and Prime Rate Behaviour in the U.S.



[1]- http://research.stlouisfed.org

[2]- http://www.nber.org/cycles.html

[3]- http://www.cdhowe.org/c-d-howe-institute-business-cycle-council-issues-authoritative-dates-for-the-2008-2009-recession

Figure (1-2) - Federal Funds Rate and 6-Month Treasury Bill Rate Behaviour in the U.S.

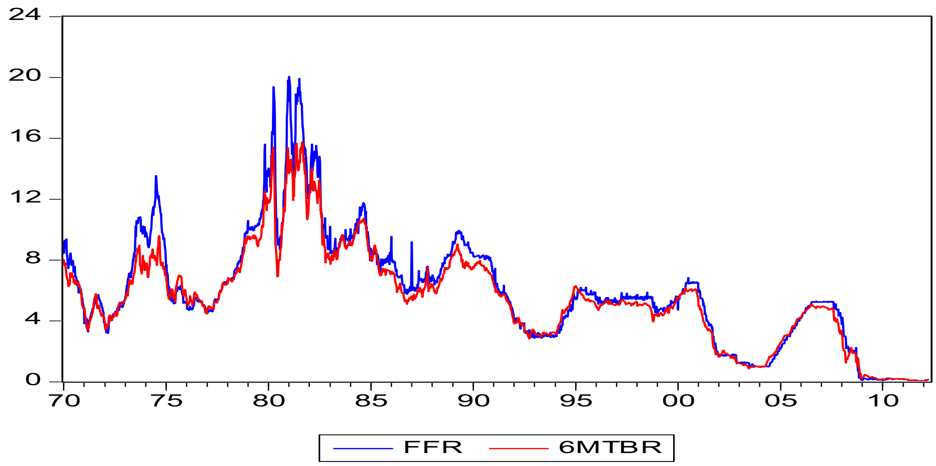


Figure (1-3) - Federal Funds Rate and 10-Year Government Bond Rate Behaviour in the U.S.

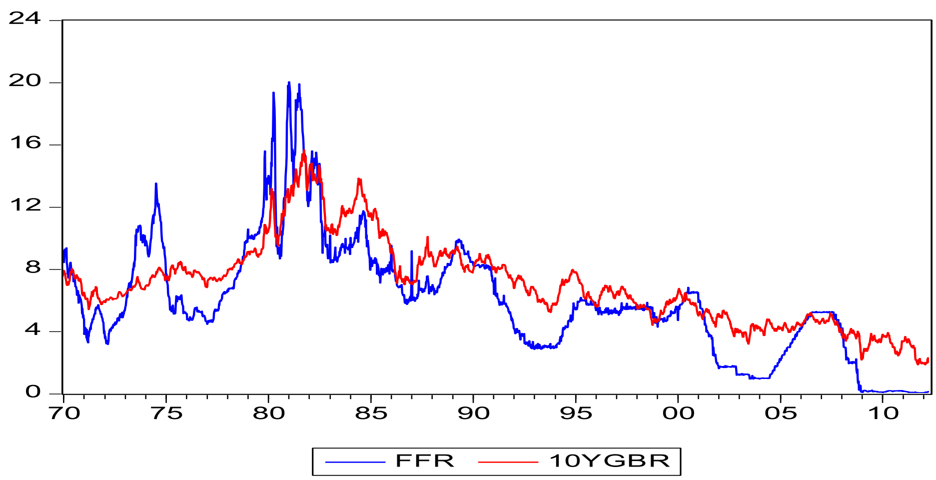


Figure (1-4) - Federal Funds Rate and 30-Year Mortgage Rate Behaviour in the U.S.

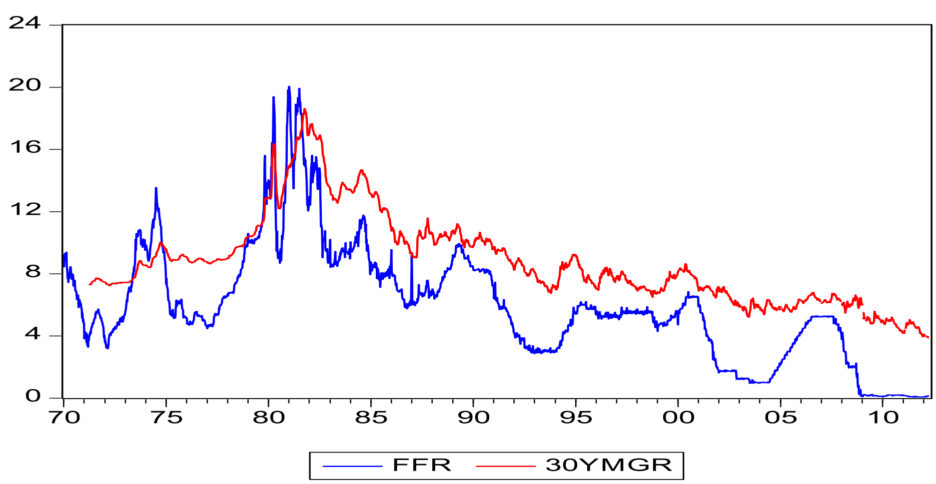


Figure (1-5) - Federal Funds Rate and BAA Corporate Bond Rate Behaviour in the U.S.

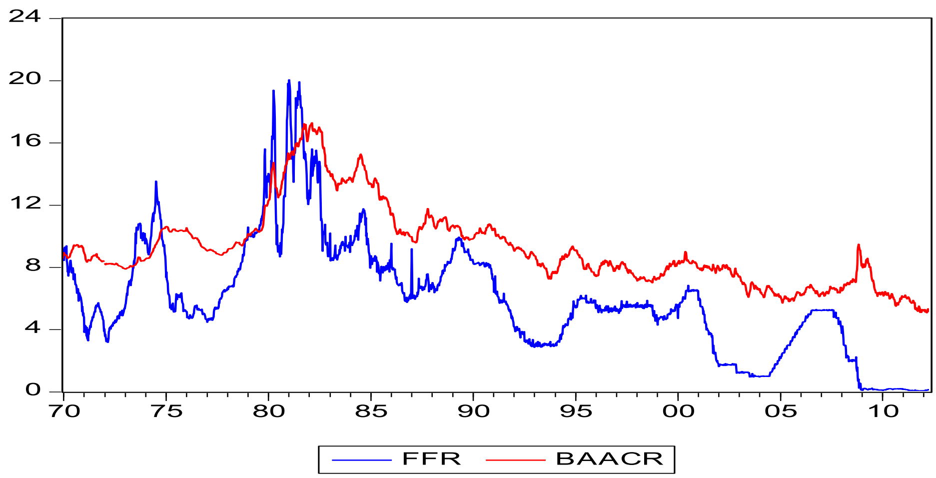


Figure (1-6) - Overnight Rate and Prime Rate Behaviour in Canada

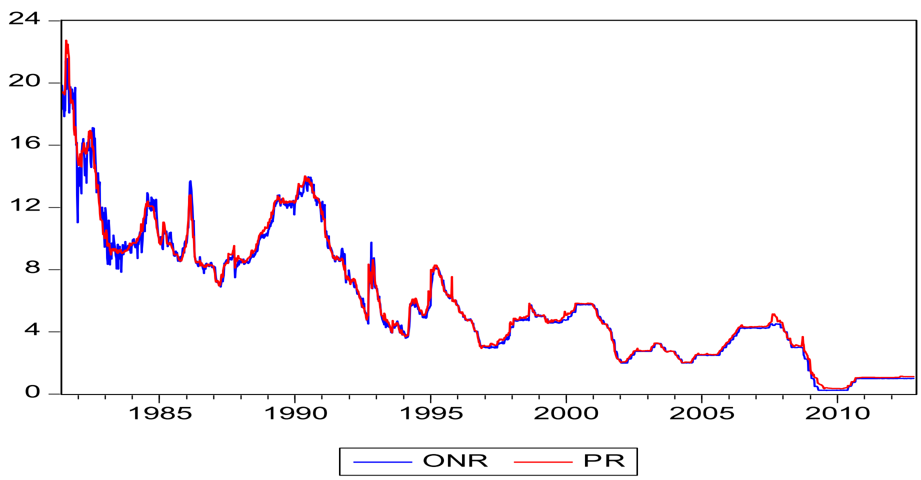


Figure (1-7) - Overnight Rate and 6-Month Treasury Bill Rate Behaviour in Canada

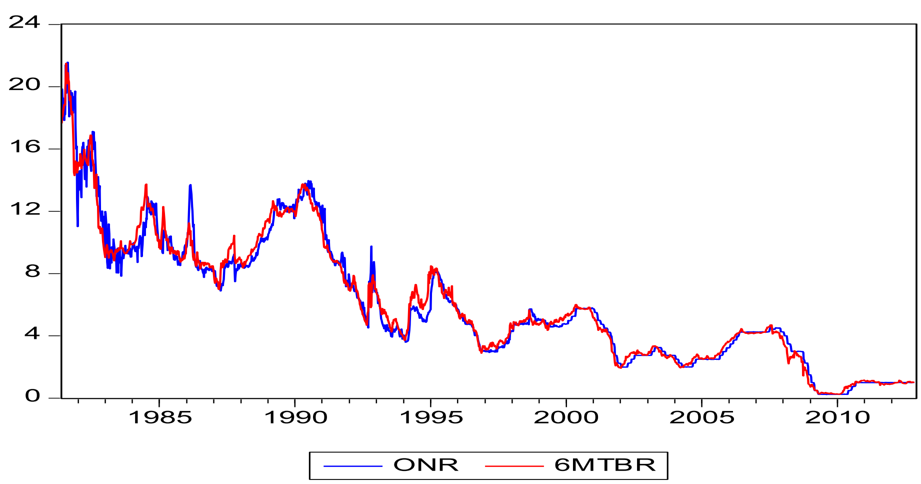


Figure (1-8) - Overnight Rate and 10-Year Government Bond Rate Behaviour in Canada

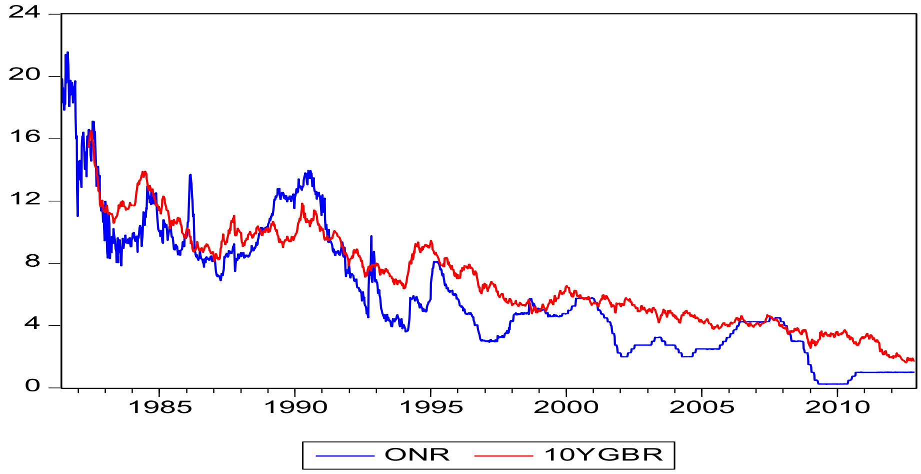


Figure (1-9) - Overnight Rate and Long-Term Government Bond Rate Behaviour in Canada

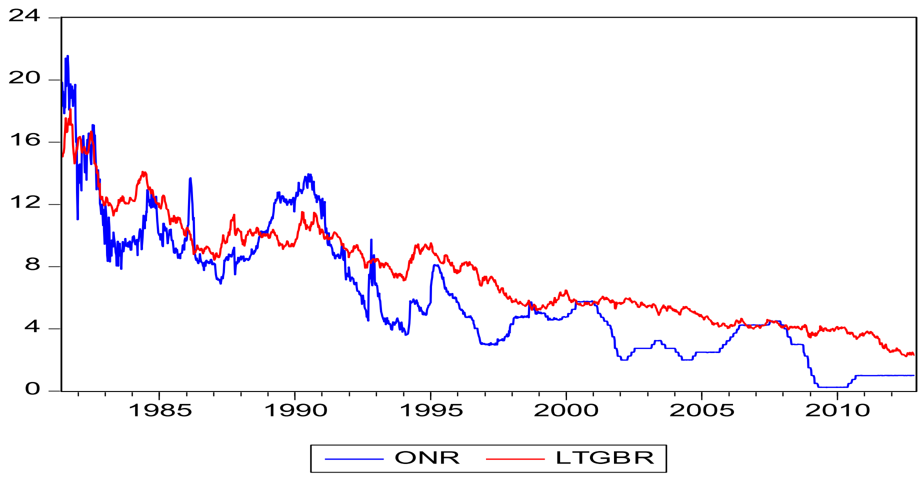
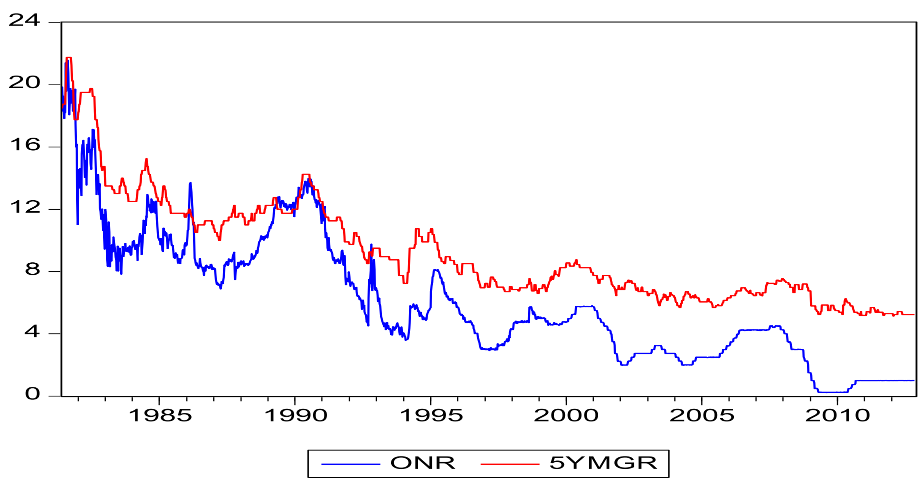


Figure (1-10) - Overnight Rate and 5-Year Mortgage Rate Behaviour in Canada



1.5.2 Unit Root Test

Before estimating five different VAR models for each business cycle, it is necessary to know the maximum order of integration of the variables in each VAR. Therefore, two different unit root tests, the Augmented Dickey-Fuller (ADF)[1] and the Philips-Peron (PP)[2] tests, are applied. The results are presented in Tables (1-1) to (1-10).[3]

As the results show, the maximum order of integration (m) in most of VAR models is one. Since both FFR and PR in business cycles 4, 6 and 7 in the U.S. are stationary, m for the related VAR model is considered zero. Also, in business cycles 2 and 3 in Canada, ONR, PR and 6MTBR are stationary. Therefore, in the VAR model including both ONR and PR, and also in the model including both ONR and 6MTBR, m is considered zero. Hence, we estimate these models like the usual VAR model.

1- Dickey and Fuller (1979)

2- Philips and Peron (1988)

3- In the Tables (1-1) to (1-10) note that:

a) The null hypothesis is that the series has a unit root.

b) *, ** and *** denote significance at the 1, 5 and 10 percent level, respectively. The critical values for the Augmented Dickey Fuller test and the Phillips-Peron test are from MacKinnon (1996). These values for the case with *intercept* are as follows:

1% level	-3.459101
5% level	-2.874086
10% level	-2.573533

and for the case with *intercept and trend* are as follows:

1% level	-4.003449
5% level	-3.431896
10% level	-3.139664

c) The number of the lags in the ADF and PP unit root tests are determined by the Schwartz Information Criteria.

Table (1-1) - Unit Root Test, Business Cycle 1 in the U.S.

(December 1969 to November 1973)

Variable	ADF		PP	
	Intercept	Intercept and Trend	Intercept	Intercept and Trend
FFR	-0.9843	-0.6324	-0.9093	-0.9428
PR	-0.7379	0.9518	-0.3386	0.8714
6MTBR	-1.2421	-1.2422	-1.2421	-1.2422
10YGBR	-2.0749	-1.9676	-1.9138	-1.7913
30YMR	-0.8797	-1.4362	0.1625	-0.6771
BAACR	-1.5509	-2.4066	-1.4578	-2.4029
D(FFR)	-5.3190*	-18.8067*	-17.6358*	-18.1447*
D(PR)	-4.7170*	-9.7195*	-9.6013*	-10.2042*
D(6MTBR)	-10.5493*	-10.9182*	-10.8775*	-11.1113*
D(10YGBR)	-9.6649*	-9.6715*	-9.7154*	-9.7143*
D(30YMR)	-3.9470*	-3.9775*	-7.7971*	-7.8361*
D(BAACR)	-7.8584*	-7.8369*	-7.7865*	-7.7662*

Table (1-2) - Unit Root Test, Business Cycle 2 in the U.S.

(November 1973 to January 1980)

Variable	ADF		PP	
	Intercept	Intercept and Trend	Intercept	Intercept and Trend
FFR	-0.0378	-0.1851	0.0781	-0.3097
PR	-0.1843	-0.5479	0.2943	-0.1195
6MTBR	-0.1105	-0.9148	0.1364	-0.7099
10YGBR	-0.1969	-1.1704	0.5876	-0.7108
30YMR	1.6576	0.4329	2.2669	0.7963
BAACR	0.1239	-0.1503	0.2317	-0.0416
D(FFR)	-15.5155*	-15.8360*	-15.5167*	-15.7574*
D(PR)	-5.9180*	-6.1710*	-8.6806*	-9.0513*
D(6MTBR)	-13.9016*	-14.0731*	-13.7493*	-13.8140*
D(10YGBR)	-13.2534*	-13.2800*	-13.2880*	-13.3016*
D(30YMR)	-8.1648*	-8.4648*	-12.2852*	-12.4322*
D(BAACR)	-7.7998*	-7.8697*	-7.8476*	-7.9242*

Table (1-3) - Unit Root Test, Business Cycle 3 in the U.S.

(January 1980 to July 1981)

Variable	ADF		PP	
	Intercept	Intercept and Trend	Intercept	Intercept and Trend
FFR	-1.1255	-1.6549	-1.3675	-1.8320
PR	-1.9602	-2.7824	-1.4534	-1.7563
6MTBR	-1.4957	-1.8759	-1.5275	-1.8701
10YGBR	-1.4448	-2.1956	-1.2482	-1.8938
30YMR	-2.2422	-2.9986	-1.3373	-1.8707
BAACR	-1.3506	-2.2806	-1.2595	-1.9696
D(FFR)	-6.7378*	-6.7654*	-6.9711*	-6.9874*
D(PR)	-3.4281**	-3.4182***	-3.5263*	-3.5206**
D(6MTBR)	-5.8157*	-5.8023*	-5.9499*	-5.9375*
D(10YGBR)	-6.1510*	-6.1133*	-6.0730*	-6.0332*
D(30YMR)	-2.9883**	-2.9743	-4.6279*	-4.6116*
D(BAACR)	-4.5270*	-4.4987*	-4.4852*	-4.4568*

Table (1-4) - Unit Root Test, Business Cycle 4 in the U.S.

(July 1981 to July 1990)

Variable	ADF		PP	
	Intercept	Intercept and Trend	Intercept	Intercept and Trend
FFR	-4.037853*	-3.365805***	-3.987306*	-3.370314***
PR	-3.7389*	-2.5144	-3.4502**	-2.4705
6MTBR	-2.5594	-2.1736	-2.5496	-2.1833
10YGBR	-1.7216	-2.0546	-1.6506	-1.9702
30YMR	-1.6105	-1.9050	-1.5717	-1.7441
BAACR	-1.3442	-1.7413	-1.2699	-1.6691
D(FFR)	-26.4246*	-26.6279*	-26.3935*	-26.6878*
D(PR)	-8.3675*	-14.4279*	-15.5303*	-15.5491*
D(6MTBR)	-17.3372*	-17.4111*	-17.4930*	-17.5312*
D(10YGBR)	-16.3597*	-16.3614*	-16.3290*	-16.3158*
D(30YMR)	-9.9756*	-10.0020*	-14.6004*	-14.5896*
D(BAACR)	-13.0412*	-13.0486*	-12.9936*	-12.9914*

Table (1-5) - Unit Root Test, Business Cycle 5 in the U.S.

(July 1990 to March 2001)

Variable	**ADF**		**PP**	
	Intercept	Intercept and Trend	Intercept	Intercept and Trend
FFR	-2.9356**	-3.4133***	-2.6498***	-3.1607***
PR	-1.7180	-2.4479	-1.7743	-2.4324
6MTBR	-2.5750***	-2.8383	-2.6145***	-2.8382
10YGBR	-1.7700	-2.2977	-1.8676	-2.4544
30YMR	-2.2052	-2.2238	-2.3360	-2.4782
BAACR	-2.0425	-1.9622	-2.0460	-1.9397
D(FFR)	-3.8844*	-19.1038*	-35.0421*	-35.9365*
D(PR)	-19.0878*	-19.2038*	-19.5481*	-19.5894*
D(6MTBR)	-16.6839*	-16.7645*	-17.6388*	-17.5233*
D(10YGBR)	-19.6704*	-19.6550*	-19.9015*	-19.8862*
D(30YMR)	-22.8996*	-22.8995*	-23.0934*	-23.0888*
D(BAACR)	-18.9422*	-18.9589*	-18.94508*	-18.9293*

Table (1-6) - Unit Root Test, Business Cycle 6 in the U.S.

(March 2001 to December 2007)

Variable	**ADF**		**PP**	
	Intercept	Intercept and Trend	Intercept	Intercept and Trend
FFR	-1.4963	-5.0221*	-1.3099	-4.9469*
PR	-1.5302	-3.2963***	-1.3126	-4.5921*
6MTBR	-1.1644	-2.9589	-1.2081	-2.8976
10YGBR	-2.8669***	-2.8619	-2.6894***	-2.6876
30YMR	-2.3868	-2.2917	-2.3868	-2.2917
BAACR	-1.7694	-1.8138	-1.6762	-1.6458
D(FFR)	-3.3317**	-3.5027**	-22.4531*	-22.7189*
D(PR)	-3.2535**	-3.3882***	-17.4050*	-17.4577*
D(6MTBR)	-7.5523*	-7.6613*	-12.1920*	-12.2802*
D(10YGBR)	-14.1246*	-14.1041*	-14.0838*	-14.0632*
D(30YMR)	-14.8820*	-14.8827*	-15.0150*	-15.0097*
D(BAACR)	-9.1464*	-9.1740*	-13.5220*	-13.5332*

Table (1-7) - Unit Root Test, Business Cycle 7 in the U.S.

(December 2007 to May 2012)

Variable	ADF		PP	
	Intercept	Intercept and Trend	Intercept	Intercept and Trend
FFR	-5.2351*	-3.8749**	-5.7873*	-4.1225*
PR	-4.4153*	-3.8175**	-5.9025*	-4.1146*
6MTBR	-4.0579*	-2.9942	-3.8501*	-2.9780
10YGBR	-1.5635	-2.6814	-1.3655	-2.3854
30YMR	-0.5097	-2.4364	-0.7247	-2.7636
BAACR	-1.0799	-2.6929	-0.9308	-2.5540
D(FFR)	-2.7770	-16.0943*	-15.3330*	-16.1382*
D(PR)	-3.0878*	-3.7875**	-10.1180*	-10.8592*
D(6MTBR)	-5.2061*	-5.5803*	-13.9733*	-14.1805*
D(10YGBR)	-12.9600*	-12.9454*	-13.1285*	-13.1154*
D(30YMR)	-16.6574*	-16.6427*	-17.1716*	-17.2474*
D(BAACR)	-7.6397*	-7.6780*	-11.5955*	-11.6222*

Table (1-8) - Unit Root Test, Business Cycle 1 in Canada

(May 1981 to March 1990)

Variable	ADF		PP	
	Intercept	Intercept and Trend	Intercept	Intercept and Trend
ONR	-2.2804	-2.0677	-2.2465	-2.0478
PR	-2.6377***	-1.4996	-2.4555	-1.6758
6MTBR	-2.7619***	-2.0008	-2.7431***	-1.9970
10YGBR	-3.5462*	-3.0561	-2.9346**	-2.4320
LTGBR	-1.7392	-1.7265	-1.7790	-1.8778
5YMGR	-1.9748	-1.4007	-1.9331	-1.5375
D(ONR)	-24.8235*	-24.8404*	-25.5803*	-25.9698*
D(PR)	-17.7337*	-17.9683*	-18.5515*	-18.5860*
D(6MTBR)	-18.7291*	-18.9199*	-18.8394*	-18.9680*
D(10YGBR)	-11.1912*	-11.3878*	-17.8554*	-17.8855*
D(LTGBR)	-18.5955*	-18.6185*	-18.8173*	-18.8288*
D(5YMGR)	-11.6819*	-11.7707*	-17.8576*	-17.8661*

Table (1-9) - Unit Root Test, Business Cycle 2 in Canada

(March 1990 to October 2008)

Variable	ADF		PP	
	Intercept	Intercept and Trend	Intercept	Intercept and Trend
ONR	-3.1196**	-3.1018	-3.0376**	-2.9330*
PR	-3.4073**	-3.4831**	-3.3230**	-3.0300
6MTBR	-3.2804**	-3.1296	-3.1645**	-3.2323**
10YGBR	-1.9943	-3.0676	-1.9918	-3.0812
LTGBR	-1.7695	-2.8049	-1.7690	-2.8086
5YMGR	-2.5443	-2.1374	-2.5478	-2.4762
D(ONR)	-11.4525*	-11.5287*	-30.6363*	-30.6741*
D(PR)	-7.9998*	-8.1063*	-34.1446*	-34.1783*
D(6MTBR)	-19.9694*	-20.0331*	-31.4087*	-31.4000*
D(10YGBR)	-33.0645*	-33.0742*	-33.0382*	-33.0483*
D(LTGBR)	-33.5389*	-33.5488*	-33.4519*	-33.4625*
D(5YMGR)	-29.0553*	-29.1085*	-29.4564*	-29.4381*

Table (1-10) - Unit Root Test, Business Cycle 3 in Canada

(October 2008 to November 2012)

Variable	ADF		PP	
	Intercept	Intercept and Trend	Intercept	Intercept and Trend
ONR	-4.9924*	-6.0203*	-4.1662*	-4.7755*
PR	-7.9247*	-9.1859*	-5.8894*	-7.1855*
6MTBR	-3.3438**	-4.4755*	-3.3151**	-5.0072*
10YGBR	-1.1397	-2.1027	-1.0615	-2.0119
LTGBR	-0.5155	-1.7647	-0.6557	-1.9150
5YMGR	-3.6015*	-3.5620*	-3.6015*	-3.5882*
D(ONR)	-2.1387	-1.9711	-12.5103*	-12.5103*
D(PR)	-1.4321	-8.4337*	-11.8900*	-12.4481*
D(6MTBR)	-16.7732*	-17.2539*	-16.0458*	-16.0458*
D(10YGBR)	-16.4960*	-16.4590*	-16.4856*	-16.4488*
D(LTGBR)	-17.4365*	-17.4077*	-17.4200*	-17.3916*
D(5YMGR)	-14.4195*	-14.5072*	-14.4219*	-14.5068*

1.5.3 Granger Causality Test Results

For each business cycle, there were five VAR models to estimate. We chose 12 as the maximum lag; then, in order to know about the optimum lag lengths (p), the sequential modified Likelihood Ratio test statistic (LR), Final Prediction Error (FPE), Akaike Information Criterion (AIC), Schwartz Information Criterion (SC); and, Hannan-Quinn information criterion (HQ) were used. The lags most often suggested by the above criteria were selected to estimate the VAR models. In the optimal lag selection, some specification tests were also applied. For example, in order to be sure about the serially independence of the residuals, the Lagrange Multiplier (LM) test was applied and, in the case of serial correlation among the residuals, we increased the value of p. The stability condition of the VAR models in the selected lags were checked as well and none of the characteristic polynomial roots laid outside of the unit circle. To consider the structural break associated with the recession period of each business cycle, a dummy variable (as an exogenous variable) was added to the models. Then, the Wald test, according to the TY approach, was applied. The linear Granger causality test results, including the amounts of Chi-square statistics, rejection probability and the chosen lag (p + m) for each model of the seven business cycles in the U.S. and also for three business cycles in Canada are reported in Tables (1-11) to (1-20)[1]. In addition, a summary of the Granger causality directions at a 95 percent confidence level for the U.S. and Canada has been presented in Tables (1-21) and (1-22) respectively.[2]

[1]- In the Tables (5-11) to (5-20), *, *** and **** denote statistical significance at the 1, 5 and 10 percent level, respectively.

[2]- In order to ascertain the reliability of the obtained results, we followed the above procedure again with the maximum lag of 24, instead of 12. The obtained causality directions based on the new test results were exactly the same as the previous ones.

Table (1-11) - Linear Granger Causality Test Results, Business Cycle 1 in the U.S.
(December 1969 to November 1973)

Null Hypothesis	Chi-square Statistics	Probability	Lags
FFR does not cause PR	44.26954	0.0000*	5
PR does not cause FFR	2.839258	0.5851	5
FFR does not cause 6MTBR	19.67849	0.0014*	6
6MTBR does not cause FFR	16.73559	0.0050*	6
FFR does not cause 10YGBR	19.45594	0.0016*	6
10YGBR does not cause FFR	4.541868	0.4743	6
FFR does not cause 30YMR	19.05127	0.0146**	9
30YMR does not cause FFR	11.00655	0.2013	9
FFR does not cause BAACR	7.045196	0.2173	6
BAACR does not cause FFR	7.096352	0.2136	6

Table (1-12) - Linear Granger Causality Test Results, Business Cycle 2 in the U.S.
(November 1973 to January 1980)

Null Hypothesis	Chi-square Statistics	Probability	Lags
FFR does not cause PR	61.9435	0.0000*	9
PR does not cause FFR	22.1810	0.0046*	9
FFR does not cause 6MTBR	9.2844	0.0096*	3
6MTBR does not cause FFR	35.3448	0.0000*	3
FFR does not cause 10YGBR	10.2943	0.0162**	4
10YGBR does not cause FFR	22.1637	0.0001*	4
FFR does not cause 30YMR	104.1390	0.0000*	7
30YMR does not cause FFR	48.9418	0.0000*	7
FFR does not cause BAACR	6.2130	0.3998	7
BAACR does not cause FFR	40.9051	0.0000*	7

Table (1-13) - Linear Granger Causality Test Results, Business Cycle 3 in the U.S.
(January 1980 to July 1981)

Null Hypothesis	Chi-square Statistics	Probability	Lags
FFR does not cause PR	25.59972	0.0000*	3
PR does not cause FFR	4.632508	0.0986***	3
FFR does not cause 6MTBR	1.925544	0.5880	4
6MTBR does not cause FFR	27.25656	0.0000*	4
FFR does not cause 10YGBR	3.597889	0.3083	4
10YGBR does not cause FFR	27.99273	0.0000*	4
FFR does not cause 30YMR	20.2009	0.0002*	4
30YMR does not cause FFR	5.963092	0.1134	4
FFR does not cause BAACR	0.462676	0.7935	3
BAACR does not cause FFR	12.58733	0.0018*	3

Table (1-14) - Linear Granger Causality Test Results, Business Cycle 4 in the U.S.
(July 1981 to July 1990)

Null Hypothesis	Chi-square Statistics	Probability	Lags
FFR does not cause PR	126.9892	0.0000*	2
PR does not cause FFR	5.714024	0.0574***	2
FFR does not cause 6MTBR	8.064266	0.0177**	3
6MTBR does not cause FFR	87.22572	0.0000*	3
FFR does not cause 10YGBR	17.0266	0.0738***	11
10YGBR does not cause FFR	46.66509	0.0000*	11
FFR does not cause 30YMR	1.122217	0.8907	5
30YMR does not cause FFR	13.10828	0.0108**	5
FFR does not cause BAACR	5.080821	0.0788***	3
BAACR does not cause FFR	23.25445	0.0000*	3

Table (1-15) - Linear Granger Causality Test Results, Business Cycle 5 in the U.S.
(July 1990 to March 2001)

Null Hypothesis	Chi-square Statistics	Probability	Lags
FFR does not cause PR	23.27438	0.0162**	12
PR does not cause FFR	46.34415	0.0000*	12
FFR does not cause 6MTBR	2.729785	0.6040	5
6MTBR does not cause FFR	56.95891	0.0000*	5
FFR does not cause 10YGBR	12.57517	0.0277**	6
10YGBR does not cause FFR	18.42846	0.0025*	6
FFR does not cause 30YMR	6.97495	0.1372	5
30YMR does not cause FFR	16.21664	0.0027*	5
FFR does not cause BAACR	15.12667	0.0098*	6
BAACR does not cause FFR	11.05223	0.0504***	6

Table (1-16) - Linear Granger Causality Test Results, Business Cycle 6 in the U.S.
(March 2001 to December 2007)

Null Hypothesis	Chi-square Statistics	Probability	Lags
FFR does not cause PR	100.5756	0.0000*	8
PR does not cause FFR	42.0591	0.0000*	8
FFR does not cause 6MTBR	23.9128	0.0044*	10
6MTBR does not cause FFR	79.2707	0.0000*	10
FFR does not cause 10YGBR	23.4850	0.0091*	11
10YGBR does not cause FFR	19.8097	0.0311**	11
FFR does not cause 30YMR	19.7867	0.0484**	12
30YMR does not cause FFR	7.4824	0.7588	12
FFR does not cause BAACR	15.5486	0.1133	11
BAACR does not cause FFR	7.1589	0.7104	11

Table (1-17) - Linear Granger Causality Test Results, Business Cycle 7 in the U.S. (December 2007 to May 2012)

Null Hypothesis	Chi-square Statistics	Probability	Lags
FFR does not cause PR	136.0597	0.0000*	13
PR does not cause FFR	59.5787	0.0000*	13
FFR does not cause 6MTBR	38.4152	0.0000*	7
6MTBR does not cause FFR	87.2235	0.0000*	7
FFR does not cause 10YGBR	30.6107	0.0023*	13
10YGBR does not cause FFR	18.2721	0.1077	13
FFR does not cause 30YMR	34.7620	0.0003*	12
30YMR does not cause FFR	18.9513	0.0620***	12
FFR does not cause BAACR	14.9676	0.0918***	10
BAACR does not cause FFR	41.8108	0.0000*	10

Table (1-18) - Linear Granger Causality Test Results, Business Cycle 1 in Canada (May 1981 to March 1990)

Null Hypothesis	Chi-square Statistics	Probability	Lags
FFR does not cause PR	43.7625	0.0000*	10
PR does not cause FFR	135.4871	0.0000*	10
FFR does not cause 6MTBR	4.460557	0.1075	3
6MTBR does not cause FFR	11.9137	0.0026*	3
FFR does not cause 10YGBR	8.86089	0.3542	9
10YGBR does not cause FFR	43.08956	0.0000*	9
FFR does not cause 30YMR	24.58261	0.0169**	13
30YMR does not cause FFR	110.7179	0.0000*	13
FFR does not cause BAACR	16.27303	0.0227**	8
BAACR does not cause FFR	54.65483	0.0000*	8

Table (1-19) - Linear Granger Causality Test Results, Business Cycle 2 in Canada (March 1990 to October 2008)

Null Hypothesis	Chi-square Statistics	Probability	Lags
FFR does not cause PR	38.57323	0.0000*	8
PR does not cause FFR	580.4372	0.0000*	8
FFR does not cause 6MTBR	29.90893	0.0001*	7
6MTBR does not cause FFR	248.8614	0.0000*	7
FFR does not cause 10YGBR	13.46896	0.0362**	7
10YGBR does not cause FFR	55.63593	0.0000*	7
FFR does not cause 30YMR	24.55434	0.0035*	10
30YMR does not cause FFR	48.77614	0.0000*	10
FFR does not cause BAACR	13.65255	0.0338**	7
BAACR does not cause FFR	50.57516	0.0000*	7

Table (1-20) - Linear Granger Causality Test Results, Business Cycle 3 in Canada (October 2008 to November 2012)

Null Hypothesis	Chi-square Statistics	Probability	Lags
FFR does not cause PR	85.27859	0.0000*	12
PR does not cause FFR	311.5912	0.0000*	12
FFR does not cause 6MTBR	17.99055	0.0818***	11
6MTBR does not cause FFR	140.9336	0.0000*	11
FFR does not cause 10YGBR	15.68828	0.1089	11
10YGBR does not cause FFR	17.60098	0.0621***	11
FFR does not cause 30YMR	25.55329	0.0076*	12
30YMR does not cause FFR	13.37149	0.2697	12
FFR does not cause BAACR	33.84868	0.0002*	11
BAACR does not cause FFR	24.6588	0.0060*	11

Table (1-21) - Linear Granger Causality Directions
during the Last Seven Business Cycles in the U.S.

Business Cycle 1	**Business Cycle 2**	**Business Cycle 3**	**Business Cycle 4**	**Business Cycle 5**	**Business Cycle 6**	**Business Cycle 7**
$\mathrm{FFR} \overset{L}{\rightarrow} \mathrm{PR}$	$\mathrm{FFR} \overset{L}{\leftrightarrow} \mathrm{PR}$	$\mathrm{FFR} \overset{L}{\rightarrow} \mathrm{PR}$	$\mathrm{FFR} \overset{L}{\rightarrow} \mathrm{PR}$	$\mathrm{FFR} \overset{L}{\leftrightarrow} \mathrm{PR}$	$\mathrm{FFR} \overset{L}{\leftrightarrow} \mathrm{PR}$	$\mathrm{FFR} \overset{L}{\leftrightarrow} \mathrm{PR}$
$\mathrm{FFR} \overset{L}{\leftrightarrow} \mathrm{6MTBR}$	$\mathrm{FFR} \overset{L}{\leftrightarrow} \mathrm{6MTBR}$	$\mathrm{FFR} \overset{L}{\leftarrow} \mathrm{6MTBR}$	$\mathrm{FFR} \overset{L}{\leftrightarrow} \mathrm{6MTBR}$	$\mathrm{FFR} \overset{L}{\leftarrow} \mathrm{6MTBR}$	$\mathrm{FFR} \overset{L}{\leftrightarrow} \mathrm{6MTBR}$	$\mathrm{FFR} \overset{L}{\leftrightarrow} \mathrm{6MTBR}$
$\mathrm{FFR} \overset{L}{\rightarrow} \mathrm{10YGBR}$	$\mathrm{FFR} \overset{L}{\leftrightarrow} \mathrm{10YGBR}$	$\mathrm{FFR} \overset{L}{\leftarrow} \mathrm{10YGBR}$	$\mathrm{FFR} \overset{L}{\leftarrow} \mathrm{10YGBR}$	$\mathrm{FFR} \overset{L}{\leftrightarrow} \mathrm{10YGBR}$	$\mathrm{FFR} \overset{L}{\leftrightarrow} \mathrm{10YGBR}$	$\mathrm{FFR} \overset{L}{\rightarrow} \mathrm{10YGBR}$
$\mathrm{FFR} \overset{L}{\rightarrow} \mathrm{30YMR}$	$\mathrm{FFR} \overset{L}{\leftrightarrow} \mathrm{30YMR}$	$\mathrm{FFR} \overset{L}{\rightarrow} \mathrm{30YMR}$	$\mathrm{FFR} \overset{L}{\leftarrow} \mathrm{30YMR}$	$\mathrm{FFR} \overset{L}{\leftarrow} \mathrm{30YMR}$	$\mathrm{FFR} \overset{L}{\rightarrow} \mathrm{30YMR}$	$\mathrm{FFR} \overset{L}{\rightarrow} \mathrm{30YMR}$
$\mathrm{FFR} \overset{L}{\nleftrightarrow} \mathrm{BAACR}$	$\mathrm{FFR} \overset{L}{\leftarrow} \mathrm{BAACR}$	$\mathrm{FFR} \overset{L}{\leftarrow} \mathrm{BAACR}$	$\mathrm{FFR} \overset{L}{\leftarrow} \mathrm{BAACR}$	$\mathrm{FFR} \overset{L}{\rightarrow} \mathrm{BAACR}$	$\mathrm{FFR} \overset{L}{\nleftrightarrow} \mathrm{BAACR}$	$\mathrm{FFR} \overset{L}{\leftarrow} \mathrm{BAACR}$

Note: The arrows imply the direction of "Linear" (L) Granger causality which runs between series.

Table (1-22) - Linear Granger Causality Directions
during the Last Three Business Cycles in Canada

Business Cycle 1	**Business Cycle 2**	**Business Cycle 3**
$\mathrm{ONR} \overset{\mathrm{L}}{\leftrightarrow} \mathrm{PR}$	$\mathrm{ONR} \overset{\mathrm{L}}{\leftrightarrow} \mathrm{PR}$	$\mathrm{ONR} \overset{\mathrm{L}}{\leftrightarrow} \mathrm{PR}$
$\mathrm{ONR} \overset{\mathrm{L}}{\leftarrow} \mathrm{6MTBR}$	$\mathrm{ONR} \overset{\mathrm{L}}{\leftrightarrow} \mathrm{6MTBR}$	$\mathrm{ONR} \overset{\mathrm{L}}{\leftarrow} \mathrm{6MTBR}$
$\mathrm{ONR} \overset{\mathrm{L}}{\leftarrow} \mathrm{10YGBR}$	$\mathrm{ON} \overset{\mathrm{L}}{\leftrightarrow} \mathrm{10YGBR}$	$\mathrm{ONR} \overset{\mathrm{L}}{\nleftrightarrow} \mathrm{10YGBR}$
$\mathrm{ONR} \overset{\mathrm{L}}{\leftrightarrow} \mathrm{LTGBR}$	$\mathrm{ONR} \overset{\mathrm{L}}{\leftrightarrow} \mathrm{LTGBR}$	$\mathrm{ONR} \overset{\mathrm{L}}{\rightarrow} \mathrm{LTGBR}$
$\mathrm{ONR} \overset{\mathrm{L}}{\leftrightarrow} \mathrm{5YMR}$	$\mathrm{ONR} \overset{\mathrm{L}}{\leftrightarrow} \mathrm{5YMR}$	$\mathrm{ONR} \overset{\mathrm{L}}{\leftrightarrow} \mathrm{5YMR}$

The results, in Tables (1-11) to (1-17) for the U.S., show that there is a unidirectional linear Granger causality from FFR to PR in business cycles 1, 3 and 4. In the rest of the cycles, there is a bidirectional causality between these two interest rates.[1] There is also, a bidirectional linear causality between 6MTBR and FFR except for cycles 3 and 5, where we find unidirectional linear causality from 6MTBR to FFR. The results also show that in the first and last business cycles, the linear causality runs from FFR to 10YGBR while, in cycles 3 and 4 it goes in the opposite direction. Both FFR and 10YGBR causes each other in business cycles 2, 5 and 6. Moreover, while during the business cycles 1, 3, 6 and 7 the linear

[1]- As can be seen in Figures (1-1) and (1-6), in most of the time, the prime rate fluctuation is like a step function, because it is determined as the target rate of the central bank plus a mark up over the FFR or ONR. For that reason, the causality direction from FFR and ONR to the prime rate makes sense and could be expected.

causation goes from FFR to 30YMR, in cycles 4 and 5 it goes from 30YMR to FFR and in business cycle 2, there is a bidirectional causality between them.

Finally, about FFR and BAACR, the results show that in all of the business cycle except business cycles 1, 5 and 6, causality runs from BAACR to FFR. In cycles 5, it goes from FFR to BAACR and during cycles 1 and 6, there is no significant causal relationship between them.

From Tables (1-18) to (1-20) for Canada, we can see that there is a bidirectional linear Granger causality between ONR and PR[1] and also between ONR and 5YMR in all three business cycles. Moreover, the results show that while there is a unidirectional linear causality that runs from 6MTBR to ONR during cycles 1 and 3, in business cycle 2, these two interest rates cause each other significantly. We can also see that in business cycle 1, linear Granger causality runs from 10YGBR to FFR and during cycle 2, it runs both ways. However, in the last cycle, they do not cause each other significantly. Also, the results show that while there is a bidirectional linear Granger causality between ONR and LTGBR during cycles 1 and 2, there is a unidirectional causality between them in cycle 3.

By looking at Tables (1-21) and (1-22), one can see how the linear Granger causality directions change over time. In the case of the U.S., unlike what was mentioned in Pollin (2008), we cannot say that bidirectional linear causality is the most common linear causality direction between FFR and the other interest rates. As a post-Keynesian structuralist, Pollin (2008, p. 11) believes there is a *"... significant two-way causation over the full five cycles, but with this significant mutual influence apparently diminishing substantially, to the point of*

[1]- See the explanation in the previous page footnote.

insignificance, in the most recent cycle.” Furthermore, according to Pollin’s results, FFR does not Granger cause long-term market interest rates during the recent business cycles. In contrast, our findings for the last two cycles confirm the significant linear causal effect of the federal funds rate on the long-term interest rates.

Until now, all of our findings are only based on the linear Granger causality test. It is also important to apply the nonlinear Granger causality test to draw conclusions about the total Granger causality effects between different interest rates. This will be accomplished in the next chapter of the current thesis. After that, we will compare our model and also our findings with those of Pollin in more detail.

1.6 Summary and Conclusion

In this paper, with the help of time-series econometrics and by applying linear Granger-causality tests based on the Toda-Yamamoto approach, the linear causality directions between short-term and long-term interest rates during the last seven business cycles in the U.S. and the last three business cycles in Canada were investigated. A summary of the current chapter is as follows.

In section 1, the main objectives of the current study were introduced. Then the related previous studies were discussed shortly in section 2. Afterward, linear and nonlinear definitions of the Granger causality were presented in section 3. In section 4, the empirical methodology, i.e., the Toda-Yamamoto approach and also some of its advantages relative to the other approaches were explained. An explanation of the data and the results of the empirical study were presented in section 5.

In this chapter, we tried to find the linear causality relationship between the federal funds rate and overnight rate with five different interest rates, respectively, during the last seven business cycles in the U.S. and also during the last three business cycles in Canada. According to the obtained results, although Granger causality directions change over time, unlike what was shown in Pollin (2008), it cannot be said that two-way linear causality is the most common causality direction between the federal funds rate and other interest rates. Moreover, again unlike Pollin (2008), during the recent business cycles, there is a bidirectional linear Granger causality between the federal funds rate and most of the other interest rates, and the federal funds rate appeared to linearly cause the long-term interest rates significantly.

Chapter 2

Nonlinear Granger-causality between Short-term and Long-term Interest Rates during the Business Cycles

2.1 Introduction

As was mentioned in section 2 of the previous chapter, Pollin (2008) tries to measure the central banks' power to determine interest rates exogenously. In order to do so, he uses data of the last five full business cycles in the U.S. up to 2008; and, with the help of linear Granger causality tests, he examines the causality relationship between the federal funds rate and five market interest rates. While the results of causality tests for the five business cycles show that there is a significant two-way causation between the federal funds rate and the market rates, these causations are found to be insignificant for the last business cycle. Therefore, Pollin, as a post-Keynesian structuralist, concludes that market interest rates, except the prime rate, are strongly determined by endogenous market financial operations and the extent to which market rates are set exogenously by the Federal Reserve is limited.

In the previous chapter, by using linear Granger causality test, the relationships between short-term and long-term interest rates were investigated. However, these rates may also be related nonlinearly and, as discussed by Baek and Brock (1992), linear Granger causality tests cannot find nonlinear causal relationships. In the literature, there are different nonparametric causality tests without this limitation.

Baek and Brock (1992) suggest a nonlinear Granger causality test based upon the assumption that the residuals of the related VAR model are mutually independent and individually follow an i.i.d. distribution. Hiemstra and Jones (1994), by changing the assumption of Baek and Brock's test such that the residuals can also be weakly dependent, modify Baek and Brock's test. But, according to Diks and Panchenko (2005), by increasing the number of observations, Hiemstra and Jones's test statistic has a bias and tends to reject the null hypothesis of a Granger causality test in favour of its alternative when the null is true. Therefore, in order to solve this consistency problem, Diks and Panchenko (2006) propose a new nonparametric test in which the used bandwidth converges to zero appropriately.

In this paper, we apply Diks and Panchenko Granger causality test to explore the nonlinear causal relationships between short-term and long-term interest rates during the last seven business cycles in the U.S. and the last three business cycles in Canada. In the next section, our empirical methodology is explained in more detail. The empirical analysis, including the information about data sets and also the results of unit root tests and nonlinear Granger causality test are presented in section 3. Then, in section 4, we combine the obtained linear and nonlinear Granger causality directions between different interest rates. In section 5, the current study is compared with Pollin's (2008) experimental work in detail. Finally, the important elements and conclusions are summarized in section 6.

Employing nonlinear Granger causality test to explore casual relationships between interest rates and combining nonlinear causality effects with the linear ones are the contributions of the current chapter.

2.2 Empirical Methodology

In the previous chapter, we applied the Toda-Yamamoto approach to find the linear Granger causality directions between short-term and long-term interest rates in the U.S. and Canada. As was explained before, for any two variables of X_t and Y_t, we had a VAR model:

$$X_t = A_1(L)\, X_t + B_1(L)\, Y_t + U_{1t} \qquad (1)$$

$$Y_t = A_2(L)\, X_t + B_2(L)\, Y_t + U_{2t} \qquad for\;\; t = 1, 2, \dots, T \qquad (2)$$

where L is the lag operator of order d such that $d = p + m$ in which, p is the lag length of the common VAR model and m is the maximum integration order of X_t and Y_t.

Here, the Diks-Panchenko (DP) nonparametric technique is applied for the residuals of the previously estimated VAR models to detect the strictly nonlinear Granger causality impacts.

These residuals are obtained as follow for $t = 1, 2, \dots, T$:

$$\hat{U}_{1t} = X_t - \hat{A}_1(L)\, X_t - \hat{B}_1(L)\, Y_t \qquad (3)$$

$$\hat{U}_{2t} = Y_t - \hat{A}_2(L)\, X_t - \hat{B}_2(L)\, Y_t \qquad (4)$$

where $\hat{A}_i(L)$ and $\hat{B}_i(L)$ for $i = 1, 2$ are the estimated parameters.

Intuitively, applying a nonlinear Granger causality test to the residuals of the linear VAR model gives more information about the causality relationships between variables relative to the linear causality test. In other words, we try to find additional information in the residuals of the VAR model that help to predict the total distribution of the related variables and which could not be found in the linear causality test. Linear causality tests just find causality effects related to the first moment of distributions.

We start by briefly explaining the nonparametric Granger causality test that is going to be employed in this paper.

Diks-Panchenko Nonparametric Granger Causality Test [1]

Consider two strictly stationary time series X_t and Y_t. X_t Granger-causes Y_t if its current and previous values contain information, in addition to what is contained in the current and previous values of Y, that can significantly affect future values of *Y*.

In other words, X_t Granger causes Y_t if for $s \geq 1$:

$$(Y_{t+1}, \dots, Y_{t+s}) | (I_{X_t}, I_{Y_t}) \nsim (Y_{t+1}, \dots, Y_{t+s}) | (I_{Y_t}) \qquad (5)$$

I_{X_t} and I_{Y_t} contain the information in the past and current observations of X_t and Y_t respectively, and '$\sim$' denotes equivalence in distribution.

Now, consider $X_t^{l_x} = (X_{t-l_x-1}, \dots, X_t)$ and $Y_t^{l_x} = (Y_{t-l_x-1}, \dots, Y_t)$ for l_x, $l_y \geq 1$. If $s = 1$, then the null hypothesis in the non-causality Granger test can be written as follows:

$$H_0 : Y_{t+1} \; \Big| \left(X_t^{l_x};\, Y_t^{l_y} \right) \sim Y_{t+1} \Big| \; Y_t^{l_y} \qquad (6)$$

Assume $Z_t = Y_{t+1}$, then we have an invariant distribution vector $K_t = (X_t^{l_x}, Y_t^{l_y}, Z_t)$.

[1]- Diks and Panchenko (2006)

By assuming $l_x = l_y = 1$ and dropping the time indexes for simplicity, the joint and marginal probability density functions, under the null hypothesis, should fulfill the following relation:

$$\frac{f_{X,Y,Z}(x,y,z)}{f_Y(y)} = \frac{f_{X,Y}(x,y)}{f_Y(y)} \cdot \frac{f_{Y,Z}(y,z)}{f_Y(y)} \tag{7}$$

Therefore, it can be shown that H_0 can be expressed as:

$$E\left[f_{X,Y,Z}(x,y,z) f_Y(y) - f_{X,Y}(x,y) f_{Y,Z}(y,z)\right] = 0 \tag{8}$$

Which leads to the following test statistics:

$$T_n(e) = \frac{n-1}{n(n-2)} \sum_i (\hat{f}_{X,Y,Z}(X_i\ Y_i, Z_i) \hat{f}_Y(Y_i) - \hat{f}_{X,Y}(X_i, Y_i) \hat{f}_{Y,Z}(Y_i, Z_i)) \tag{9}$$

$\hat{f}_K(K_i)$ is a the local density estimator of K_i, $\hat{f}_K(K_i) = (2e)^{-d_k}(n-1)^{-1} \sum_{i,j\neq i} I_{ij}^K$ where $I(\cdot)$ is an indicator function defined by $I_{ij}^K = I(\left\|K_i - K_j\right\| < e)$ in which e is the bandwidth such that $e = Cn^{-\beta}\quad C > 0$, $\frac{1}{4} < \beta < \frac{1}{3}$.

According to Diks and Panchenko (2006), the above mentioned statistics satisfies:

$$\sqrt{n}\ \frac{(T_n(e) - q)}{S_n} \xrightarrow{D} N(0,1) \tag{10}$$

where q and S_n are the estimator of asymptotic expectation and standard error respectively.[1]

[1]- Similar explanations of this method can be found in Bekiros, Stelios and Diks (2008), Zhang, Lai and Wang (2009), Karagianni, Pempetzoglou, and Saraidaris (2009); and, Hernandez and Torero (2010).

2.3 Empirical Analysis

In conducting the DP test, for any two X and Y time series variables, we set the lag length of variable X equal to the lag length of variable Y, namely $L_x = L_y$ [1], and we apply the test for the common lag length of 1 to 6. We also set e, the bandwidth length, such that $e = 1.5\sigma$.[2]

Since, before applying the test, all variables are standardized, the standard deviation of the related series, σ, is equal to one.

2.3.1 Data

Recall from the previous chapter that our weekly data, related to the last seven business cycles in the U.S., from December 1969 to May 2012, are obtained from the Federal Reserve Bank of St. Louis database[3]. Also, the weekly data for the last three business cycles in Canada, from June 1981 to November 2012, are obtained from the Bank of Canada database. The information about the duration of the different business cycles in the U.S. and Canada have been taken from the National Bureau of Economic Research[4] and the C.D. HOWE Institute[5] respectively.

Also recall that our five different interest rates in the U.S. are as follows: prime rate (PR), 6-month Treasury bill rate (6MTBR), 10-year government bond rate (10YGBR), 30-year

[1]- According to Monte Carlo method in Hiemstra and Kramer (1997)

[2]- We also applied the test for $e = 1\sigma$ and $e = n^{-0.3}$ ($e = Cn^{-\beta}$ for $C = 1$ and $\beta = 0.3$).

[3]- http://research.stlouisfed.org

[4]- http://www.nber.org/cycles.html

[5]- http://www.cdhowe.org/c-d-howe-institute-business-cycle-council-issues-authoritative-dates-for-the-2008-2009-recession

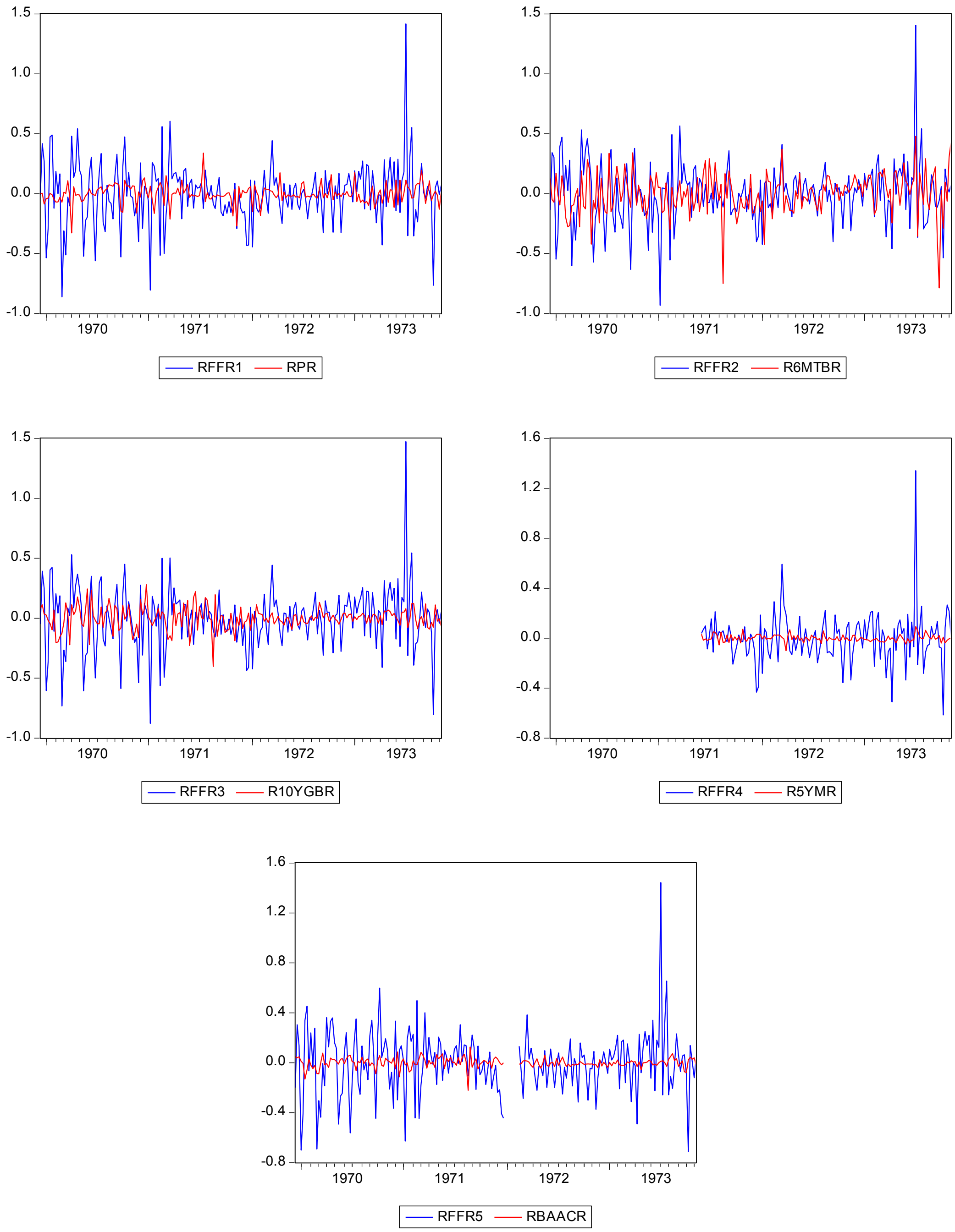
mortgage rate (30YMR) and Baa corporate bond rate (BAACR). Our interest rates in Canada are: prime rate (PR), 6-month Treasury bill rate (6MTBR), 10-year government bond rate (10YGBR), long-term government bond rate (LTGBR); and 5-year mortgage rate (5YMR).

Letter "R" in the beginning of the name of variables denotes the "residuals". For example, in every cycle, RFFR1 implies the residuals of the first equation of the VAR model in which the FRR and PR are, respectively, the dependent and explanatory variables. RPR is the residuals of the second equation in the same VAR model that contains PR as the dependent variable and FFR as the explanatory one. In the same manner, two residual series of RFFR2 and R6MTBR are obtained from the second VAR model and so on for the other variables.

The behaviour of the residuals of the previously estimated VAR models in relation to the residuals of the federal funds rate (RFFR) and the residuals of the overnight rate (RONR), for the U.S. and Canada, respectively, are illustrated in Figures (2-1) to (2-10).

It seems that all of residuals are stationary. To further examine the stationarity of the series, we apply unit root tests for them.

Figure (2-1) – The Behaviour of the residuals of the previous VAR model during Business Cycle 1 in the U.S. (December 1969 to November 1973)[1]



[1]- The disconnection in the 4th graph of this page is because of data unavailability for the 30-year mortgage rate before April 1971.

Figure (2-2) - The Behaviour of the residuals of the previous VAR model during Business Cycle 2 in the U.S. (November 1973 to January 1980)

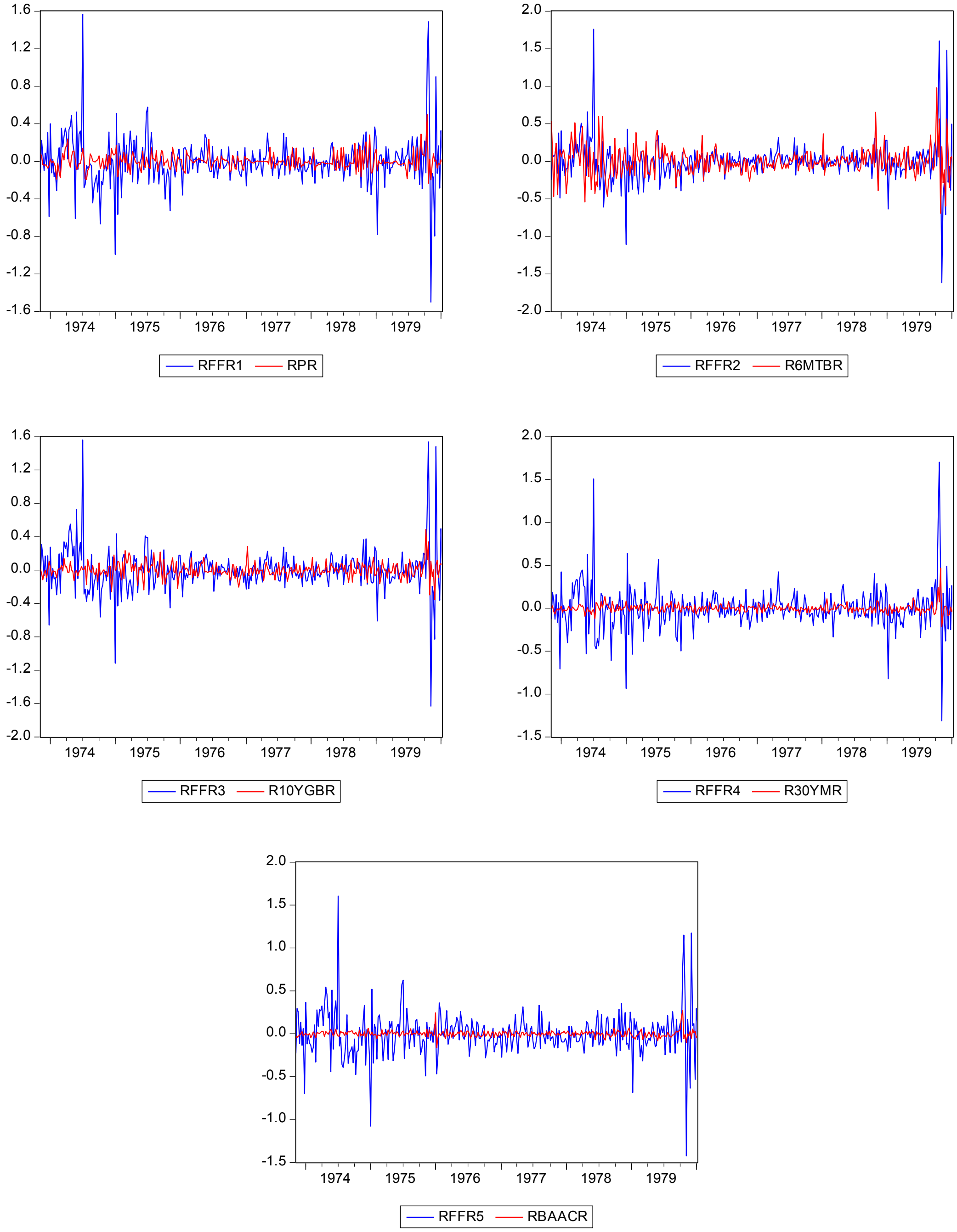


Figure (2-3) - The Behaviour of the residuals of the previous VAR model during Business Cycle 3 in the U.S. (January 1980 to July 1981)

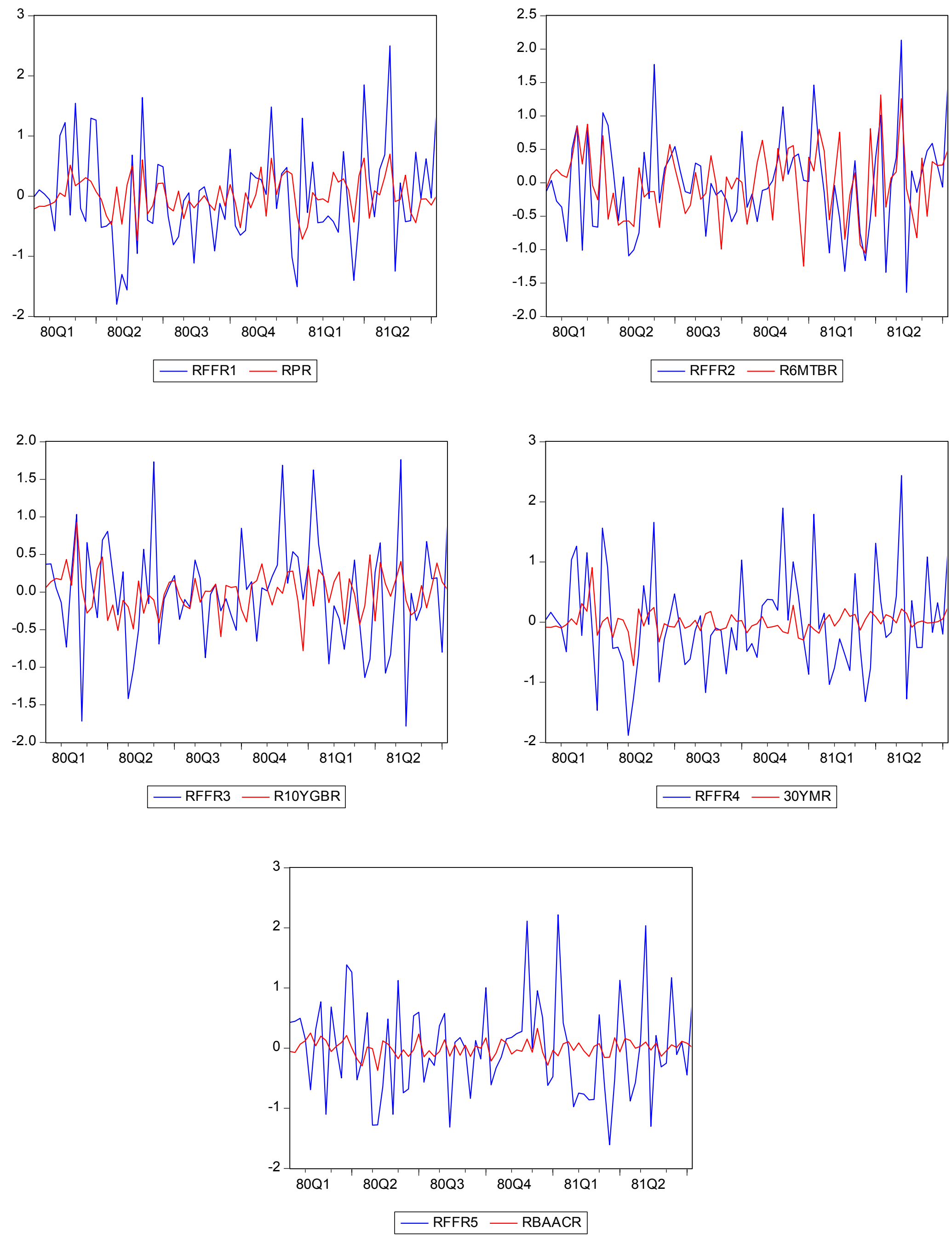


Figure (2-4) - The Behaviour of the residuals of the previous VAR model during Business Cycle 4 in the U.S. (July 1981 to July 1990)

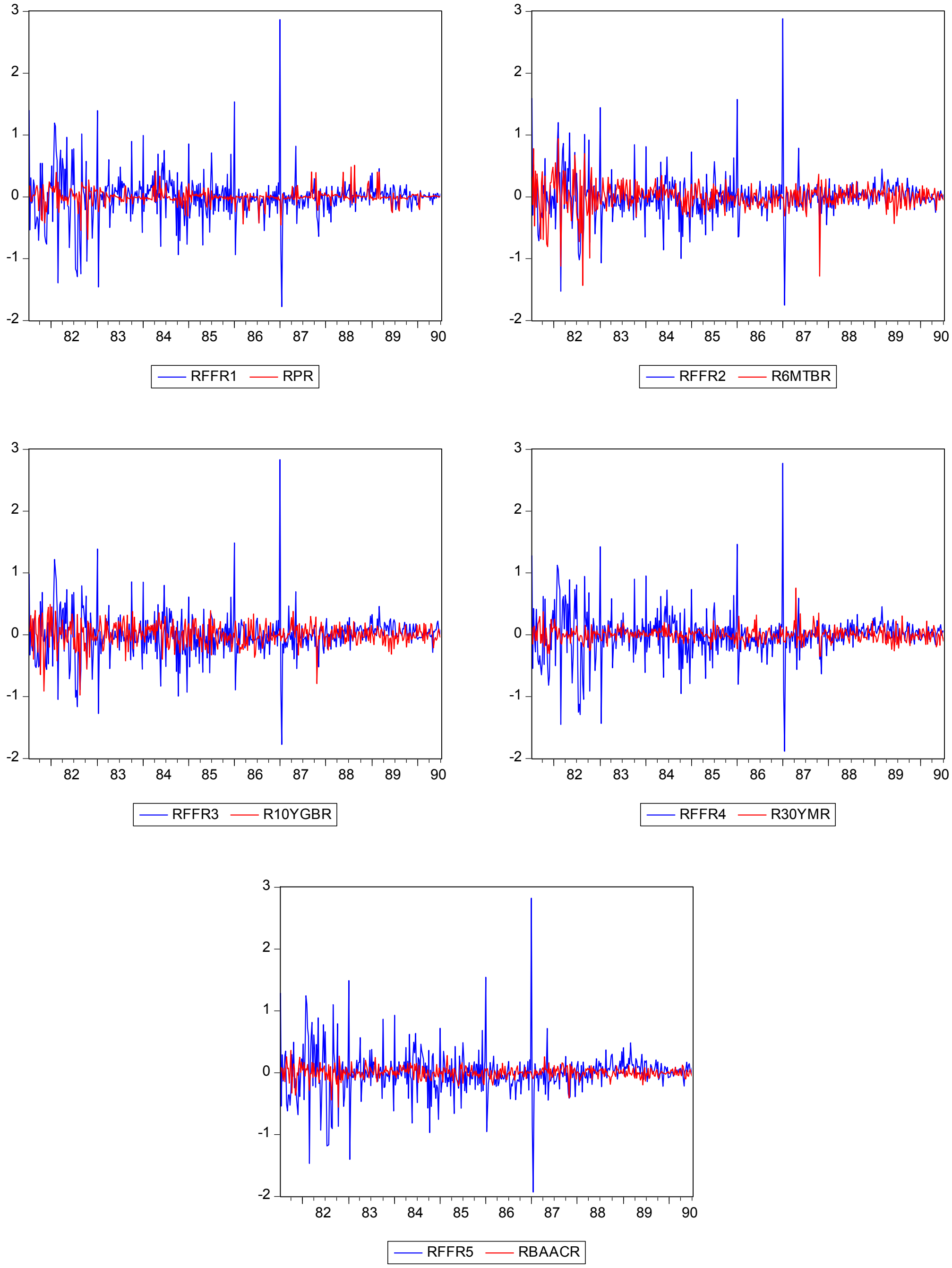


Figure (2-5) - The Behaviour of the residuals of the previous VAR model during Business Cycle 5 in the U.S. (July 1990 to March 2001)

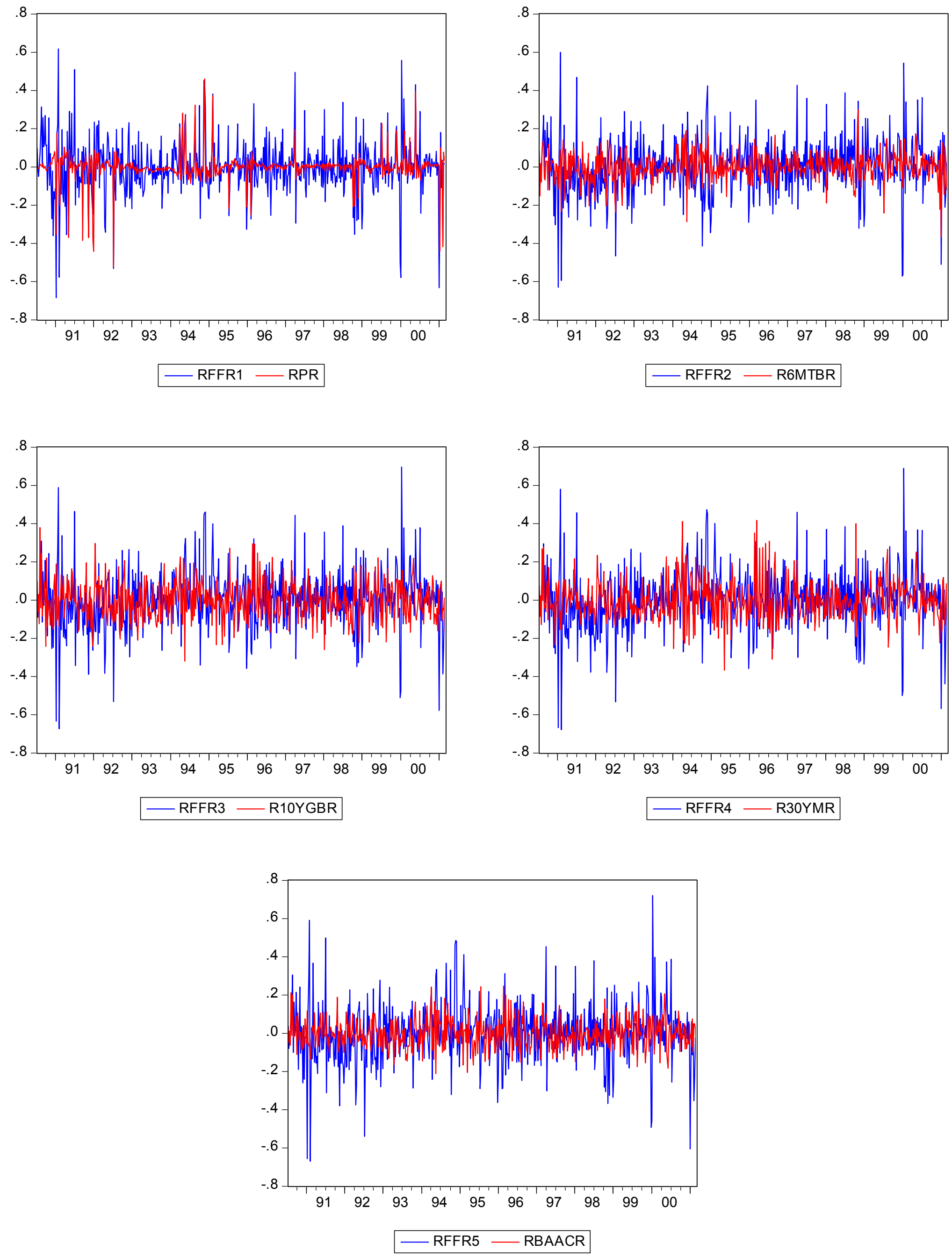


Figure (2-6) - The Behaviour of the residuals of the previous VAR model during Business Cycle 6 in the U.S. (March 2001 to December 2007)

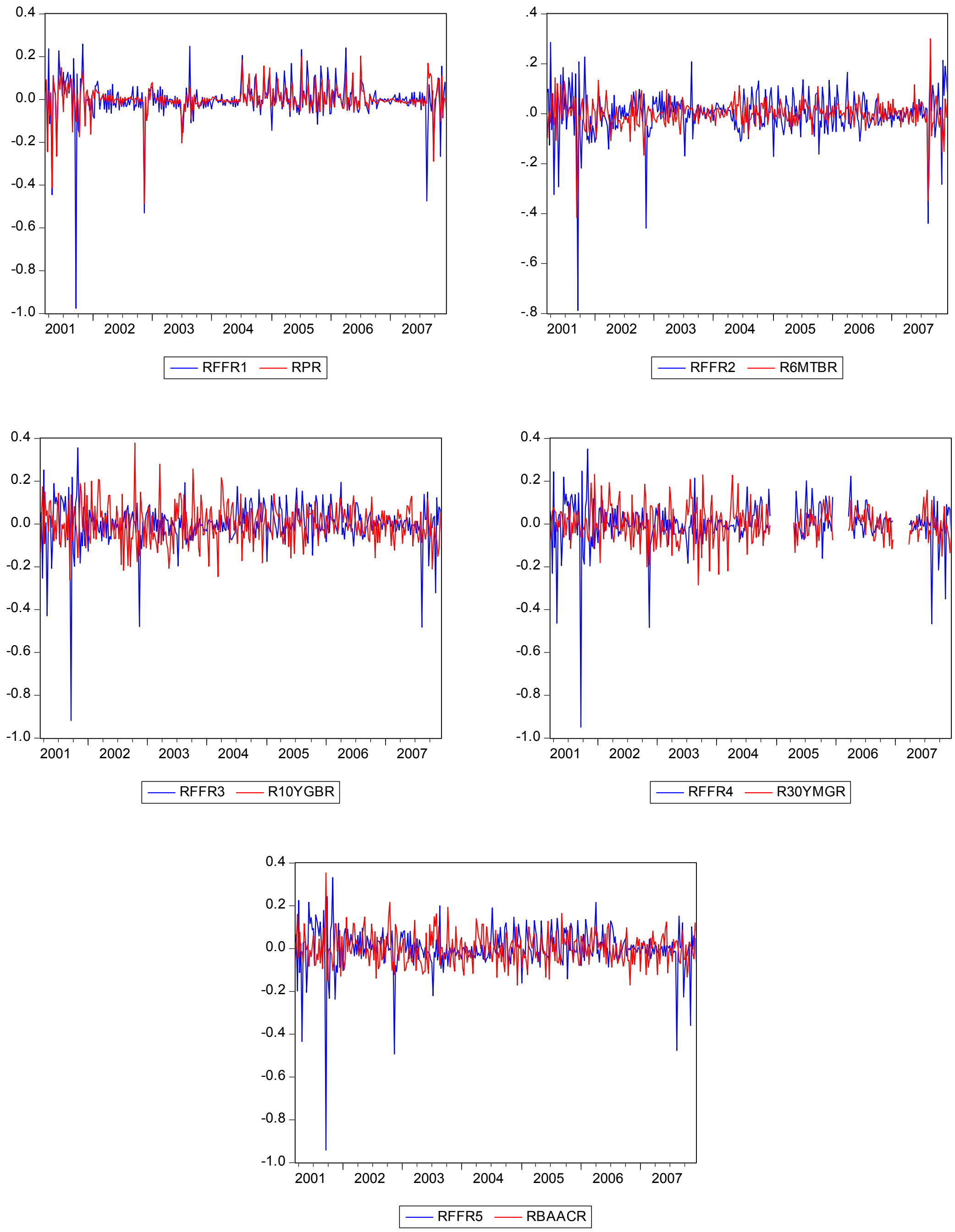


Figure (2-7) - The Behaviour of the residuals of the previous VAR model during Business Cycle 7 in the U.S. (December 2007 to May 2012)

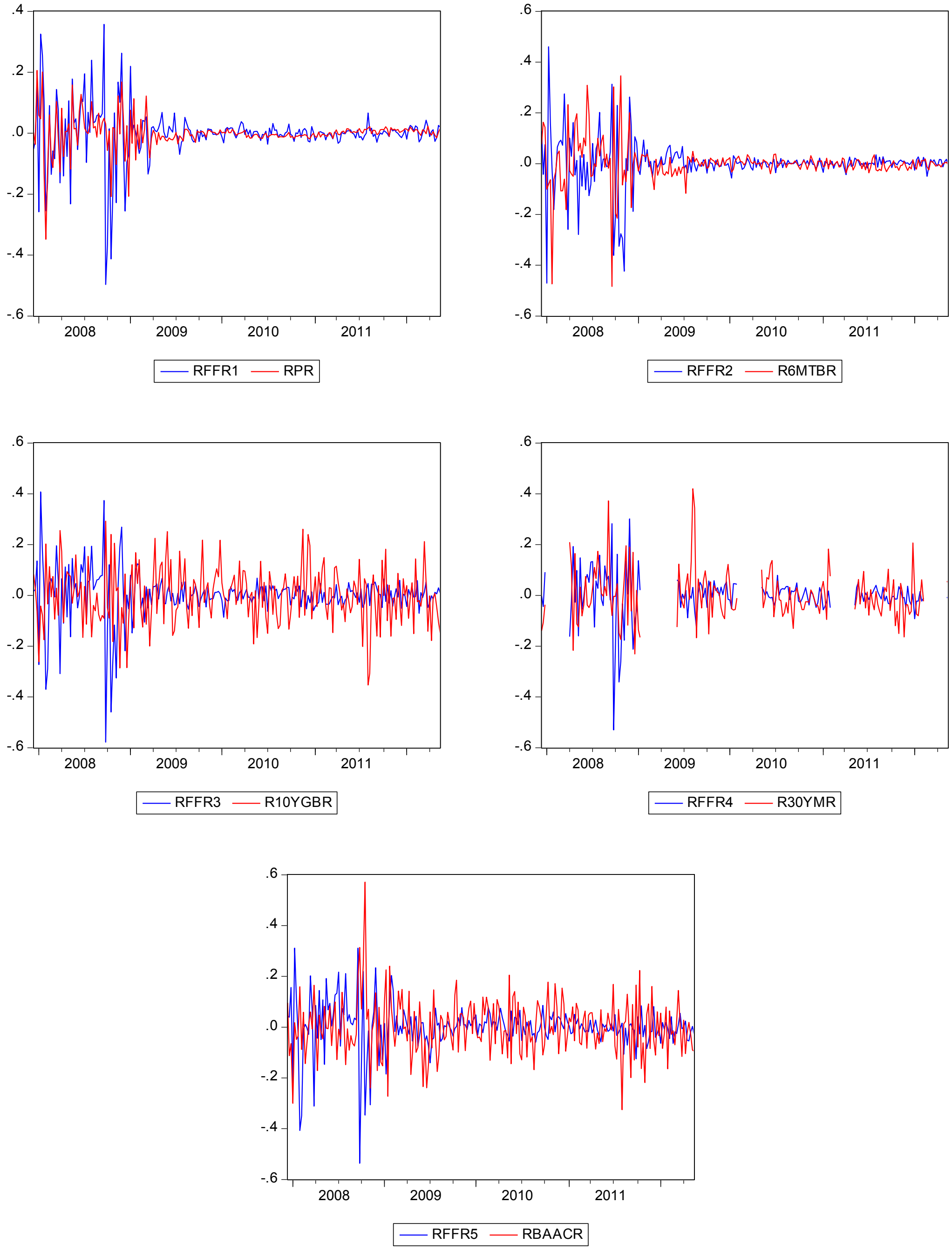


Figure (2-8) - The Behaviour of the residuals of the previous VAR model during Business Cycle 1 in Canada (October 1982 to April 1992)

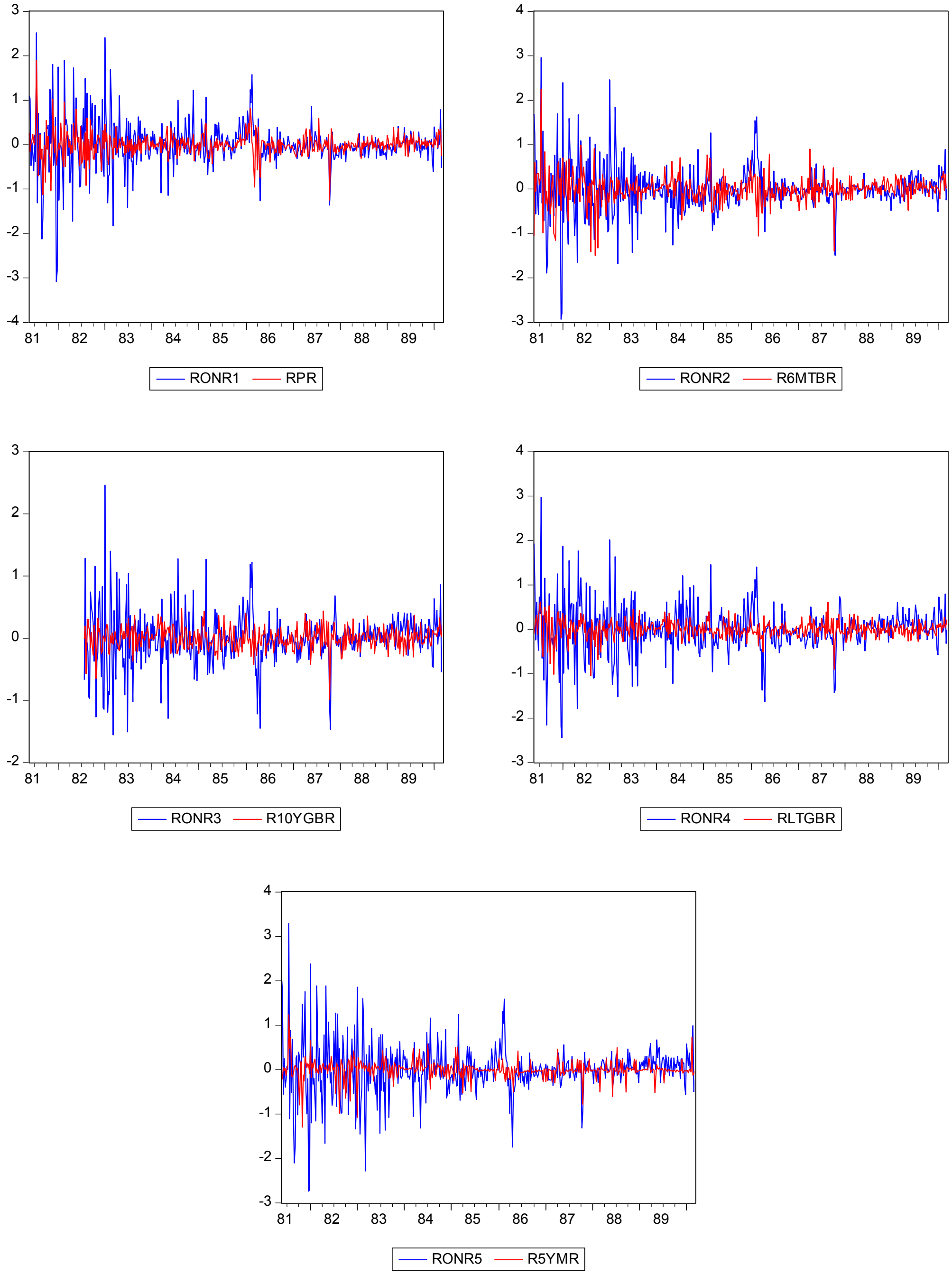


Figure (2-9) - The Behaviour of the residuals of the previous VAR model during Business Cycle 2 in Canada (April 1992 to May 2009)

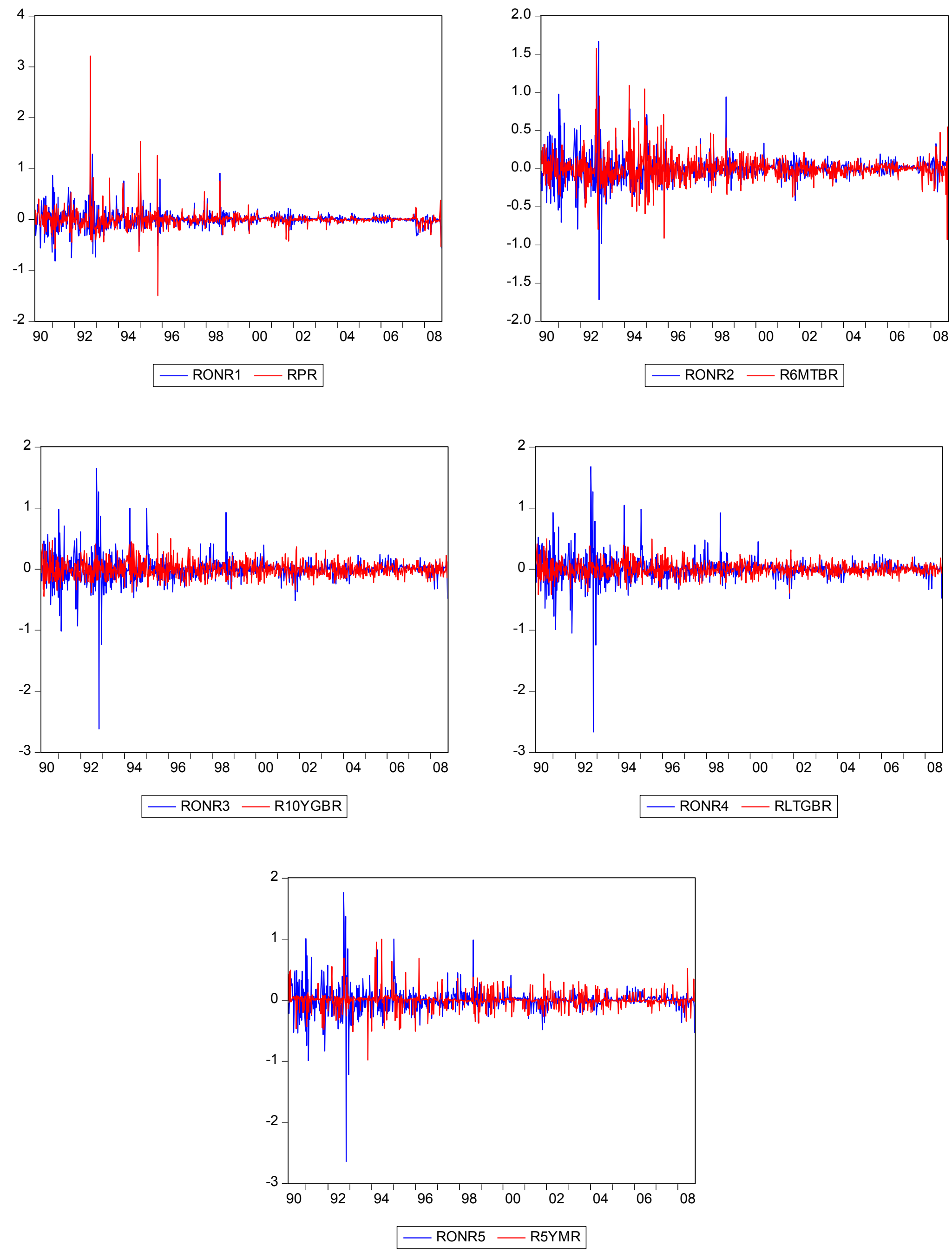
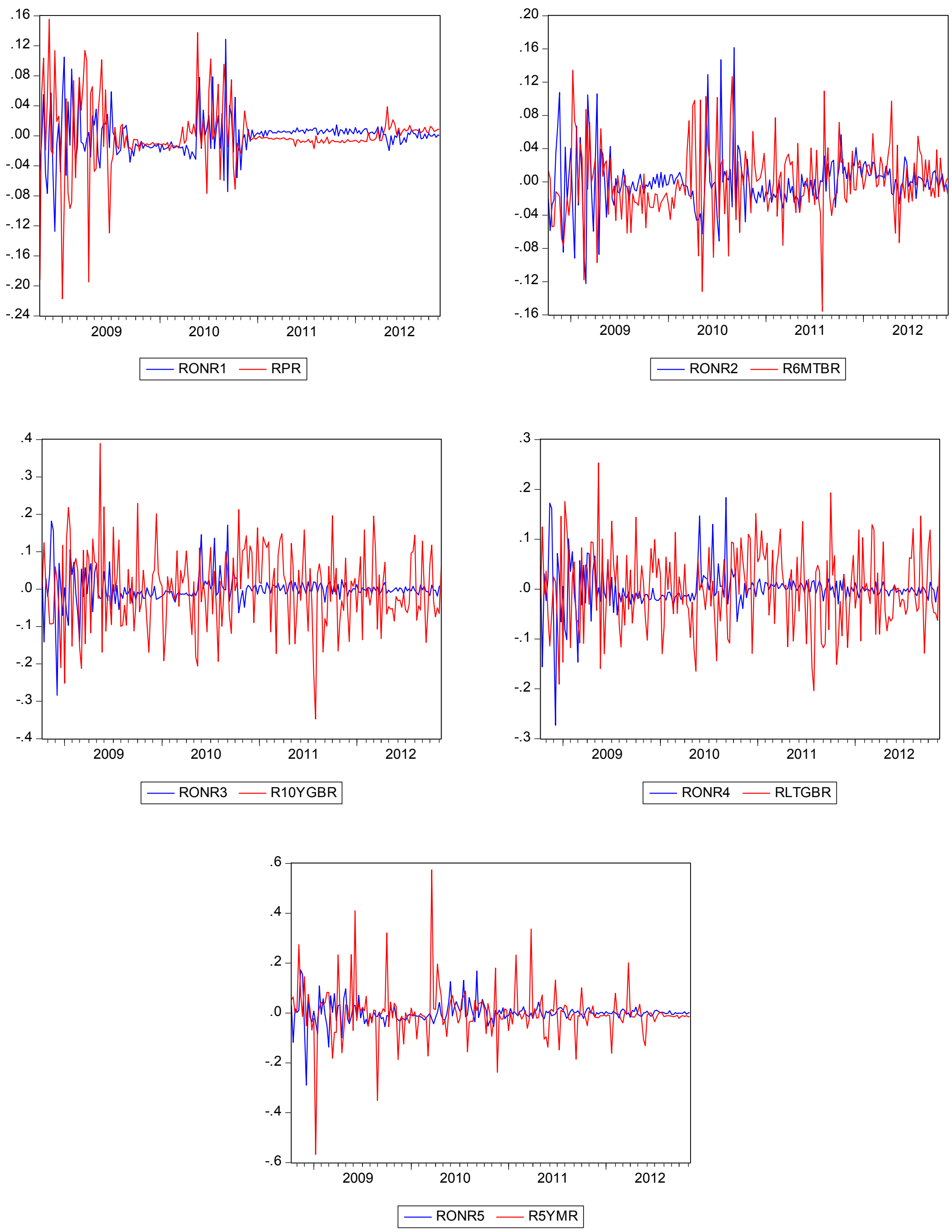


Figure (2-10) - The Behaviour of the residuals of the previous VAR model during Business Cycle 3 in Canada (May 2009 to November 2012)



2.3.2 Unit Root Test

Before applying the DP test, we use two different unit root tests, the Augmented Dickey-Fuller (ADF) [1] and the Philips-Peron (PP) [2] tests, for the residuals of the related VAR models.[3] The unit root test results for different business cycles in the U.S. and Canada are presented in Tables (2-1) to (2-10)[4].

The results show that after removing the linear impacts, all the obtained residuals are stationary.

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[1]- Dickey and Fuller (1979)

[2]- Philips and Peron (1988)

[3]- For more information about applying unit root test for the residuals see Engle and Granger (1992).

[4]- **Note:**

a) The null hypothesis is that the series has a unit root.

b) *, *** and **** denote significance at the 1, 5 and 10 percent level, respectively. The critical values for the Augmented Dickey Fuller test and the Phillips-Peron test are from MacKinnon (1996). These values for the case with *intercept* are as follows:

1% level -3.459101
5% level -2.874086
10% level -2.573533

and for the case with *intercept and trend* are as follows:

1% level -4.003449
5% level -3.431896
10% level -3.139664

and for the case with *no intercept and no trend* are as follows:

1% level -2.573751
5% level -1.942031
10% level -1.615897

c) The number of the lags in the ADF and PP unit root tests are determined by the Schwartz Information Criteria.

Table (2-1) - Unit Root Test for the Residuals, Business Cycle 1 in the U.S.

(December 1969 to November 1973)

Variable	ADF			PP		
	Intercept	Intercept and Trend	None	Intercept	Intercept and Trend	None
RFFR1	-14.2800*	-14.2868*	-14.3153*	-14.2803*	-14.2876*	-14.3159*
RPR	-14.1968*	-14.1803*	-14.2319	-14.1971*	-14.1805*	-14.2328*
RFFR2	-14.2062*	-14.2143*	-14.2413*	-14.2062*	-14.2143*	-14.2413*
R6MTBR	-13.8942*	-14.0651*	-13.9290*	-13.8945*	-14.0652*	-13.9292*
RFFR3	-14.3484*	-14.3943*	-14.3839*	-14.3484*	-14.3943*	-14.3839*
R10YGBR	-14.2258*	-14.1954*	-14.2612*	-14.2258*	-14.1954*	-14.2612*
RFFR4	-11.2410*	-11.2117*	-11.2858*	-11.2410*	-11.2117*	-11.2858*
R30YMR	-11.1546*	-11.1525*	-11.1986*	-11.1547*	-11.1525*	-11.1987*
RFFR5	-13.8681*	-13.8427*	-13.9040*	-13.8680*	-13.8425*	-13.9040*
RBAACR	-14.0925*	-14.0609*	-14.1289*	-14.1078*	-14.0749*	-14.1455*

Table (2-2) - Unit Root Test for the Residuals, Business Cycle 2 in the U.S.

(November 1973 to January 1980)

Variable	ADF			PP		
	Intercept	Intercept and Trend	None	Intercept	Intercept and Trend	None
RFFR1	-17.7865*	-17.7587*	-17.8143*	-17.7882*	-17.7607*	-17.8158*
RPR	-17.9093*	-17.8890*	-17.9373*	-17.9108*	-17.8904*	-17.9391*
RFFR2	-17.9816*	-17.9528*	-18.0095*	-17.9817*	-17.9528*	-18.0097*
R6MTBR	-18.4241*	-18.4086*	-18.4526*	-18.4117*	-18.3966*	-18.4393*
RFFR3	-17.9851*	-17.9569*	-18.0132*	-17.9851*	-17.9569*	-18.0132*
R10YGBR	-17.8068*	-17.7812*	-17.8346*	-17.8099*	-17.7848*	-17.8374*
RFFR4	-17.9554*	-17.9335*	-17.9834*	-17.9554*	-17.9335*	-17.9834*
R30YMR	-17.7959*	-17.7715*	-17.8237*	-17.7971*	-17.7728*	-17.8247*
RFFR5	-18.0221*	-17.9950*	-18.0502*	-18.0221*	-17.9954*	-18.0499*
RBAACR	-17.8750*	-17.8651*	-17.9029*	-17.8750*	-17.8651*	-17.9028*

Table (2-3) - Unit Root Test for the Residuals, Business Cycle 3 in the U.S.

(January 1980 to July 1981)

Variable	ADF			PP		
	Intercept	Intercept and Trend	None	Intercept	Intercept and Trend	None
RFFR1	-8.5894*	-8.5963*	-8.6479*	-8.5894*	-8.5962*	-8.6479*
RPR	-8.7706*	-8.7330*	-8.8278*	-8.7802*	-8.7442*	-8.8351*
RFFR2	-8.5363*	-8.5218*	-9.1661*	-8.5363*	-8.5218*	-9.1747*
R6MTBR	-8.6816*	-8.6311*	-8.5961*	-8.6817*	-8.6312*	-8.5961*
RFFR3	-9.1065*	-9.0437*	-9.1661*	-9.1137*	-9.0490*	-9.1747*
R10YGBR	-8.7482*	-8.6908*	-8.8055*	-8.7482*	-8.6908*	-8.8055*
RFFR4	-8.6420*	-8.6155*	-8.7003*	-8.6420*	-8.6155*	-8.7003*
R30YMR	-8.6846*	-8.6646*	-8.7435*	-8.6990*	-8.6795*	-8.7557*
RFFR5	-9.0524*	-8.9900*	-9.1115*	-9.0534*	-8.9907*	-9.1127*
RBAACR	-8.8833*	-8.8276*	-8.9415*	-8.8835*	-8.8277*	-8.9418*

Table (2-4) - Unit Root Test for the Residuals, Business Cycle 4 in the U.S.

(July 1981 to July 1990)

Variable	ADF			PP		
	Intercept	Intercept and Trend	None	Intercept	Intercept and Trend	None
RFFR1	-21.9295*	-21.9052*	-21.9522*	-21.9416*	-21.9170*	-21.9646*
RPR	-21.4420*	-21.4196*	-21.4649*	-21.4410*	-21.4182*	-21.4643*
RFFR2	-22.3172*	-22.3591*	-22.3399*	-22.4982*	-22.5922*	-22.5218*
R6MTBR	-21.6092*	-21.5978*	-21.6321*	-21.6098*	-21.5984*	-21.6326*
RFFR3	-21.6402*	-21.6656*	-21.6627*	-21.6421*	-21.6689*	-21.6648*
R10YGBR	-21.7852*	-21.7914*	-21.7988*	-21.7856*	-21.7929*	-21.7992*
RFFR4	-21.9907*	-21.9932*	-22.0135*	-22.0022*	-22.0052*	-22.0253*
R30YMR	-21.7033*	-21.7577*	-21.7264*	-21.7057*	-21.7578*	-21.7284*
RFFR5	-21.7940*	-21.8151*	-21.8167*	-21.8421*	-21.8729*	-21.8657*
RBAACR	-21.6070*	-21.6118*	-21.6301*	-21.6149*	-21.6181*	-21.6375*

Table (2-5) - Unit Root Test for the Residuals, Business Cycle 5 in the U.S.

(July 1990 to March 2001)

Variable	ADF			PP		
	Intercept	Intercept and Trend	None	Intercept	Intercept and Trend	None
RFFR1	-23.4442*	-23.4236*	-23.4653*	-23.4439*	-23.4232*	-23.4652*
RPR	-23.7040*	-23.7503*	-23.7254*	-23.7625*	-23.8678*	-23.7854*
RFFR2	-23.5468*	-23.9757*	-23.5681*	-23.5517*	-24.1965*	-23.5735*
R6MTBR	-23.6541*	-23.7359*	-23.6754*	-23.6541*	-23.7363*	-23.6754*
RFFR3	-23.6351*	-23.8427*	-23.6565*	-23.6432*	-23.8542*	-23.6651*
R10YGBR	-23.5205*	-23.4999*	-23.5417*	-23.5205*	-23.4999*	-23.5417*
RFFR4	-23.7385*	-23.9622*	-23.7600*	-23.7385*	-23.9622*	-23.7691*
R30YMR	-23.5303*	-23.5115*	-23.5516*	-23.5303*	-23.5115*	-23.5516*
RFFR5	-23.5877*	-23.6610*	-23.6089*	-23.5913*	-23.6744*	-23.6130*
RBAACR	-23.5614*	-23.5406*	-23.5827*	-23.5614*	-23.5406*	-23.5827*

Table (2-6) - Unit Root Test for the Residuals, Business Cycle 6 in the U.S.

(March 2001 to December 2007)

Variable	ADF			PP		
	Intercept	Intercept and Trend	None	Intercept	Intercept and Trend	None
RFFR1	-19.0772*	-19.0706*	-19.1045*	-19.0768*	-19.0688*	-19.1041*
RPR	-19.2892*	-19.3056*	-19.3168*	-19.2919*	-19.3104*	-19.3196*
RFFR2	-18.9202*	-18.9599*	-18.9471*	-18.9460*	-19.0131*	-18.9739*
R6MTBR	-18.4586*	-18.4367*	-18.4852*	-18.4575*	-18.4355*	-18.4842*
RFFR3	-18.7004*	-18.7077*	-18.7272*	-18.7664*	-18.8179*	-18.7956*
R10YGBR	-18.7185*	-18.7315*	-18.7453*	-18.7185*	-18.7314*	-18.7453*
RFFR4	-17.3885*	-17.3701*	-17.4172*	-17.3884*	-17.3700*	-17.4172*
R30YMR	-17.3357*	-17.3533*	-17.3633*	-17.3357*	-17.3533*	-17.3633*
RFFR5	-18.7494*	-18.7225*	-18.7763*	-18.7524*	-18.7249*	-18.7798*
RBAACR	-18.7494*	-18.7225*	-18.7763*	-18.7524*	-18.7249*	-18.7798*

Table (2-7) - Unit Root Test for the Residuals, Business Cycle 7 in the U.S. (December 2007 to May 2012)

Variable	ADF			PP		
	Intercept	Intercept and Trend	None	Intercept	Intercept and Trend	None
RFFR1	-15.0506*	-15.0177*	-15.0834*	-15.0510*	-15.0181*	-15.0837*
RPR	-10.6053*	-10.5860*	-10.6287*	-14.9487*	-14.9228*	-14.9813*
RFFR2	-15.5331*	-15.5067*	-15.5667*	-15.5338*	-15.5075*	-15.5675*
R6MTBR	-14.9834*	-14.9684*	-15.0159*	-14.9915*	-14.9771*	-15.0234*
RFFR3	-15.2595*	-15.2261*	-15.2927*	-15.2686*	-15.2342*	-15.3029*
R10YGBR	-15.3346*	-15.3565*	-15.3685*	-15.3347*	-15.3577*	-15.3687*
RFFR4	-13.0417*	-13.0276*	-13.0850*	-13.0288*	-13.0155*	-13.0713*
R30YMR	-11.6260*	-11.6735*	-11.6647*	-11.6295*	-11.6715*	-11.6679*
RFFR5	-15.1088*	-15.1115*	-15.1418*	-15.1088*	-15.1115*	-15.1418*
RBAACR	-15.5954*	-15.5827*	-15.6296*	-15.5938*	-15.5813*	-15.6278*

Table (2-8) - Unit Root Test for the Residuals, Business Cycle 1 in Canada (October 1982 to April 1992)

Variable	ADF			PP		
	Intercept	Intercept and Trend	None	Intercept	Intercept and Trend	None
RONR1	-21.3744*	-21.3673*	-21.3976*	-21.3744v	-21.3673*	-21.3976*
RPR	-21.3557*	-21.3348*	-21.3790*	-21.3557*	-21.3347*	-21.3791*
RONR2	-21.4515*	-21.4424*	-21.4745*	-21.4515*	-21.4424*	-21.4745*
R6MTBR	-21.3576*	-21.3418*	-21.3805*	-21.3643*	-21.3485*	-21.3865*
RONR3	-19.7413*	-19.8298*	-19.7661*	-19.7425*	-19.8298*	-19.7672*
R10YGBR	-19.8345*	-19.8104*	-19.8596*	-19.8342*	-19.8099*	-19.8594*
RONR4	-21.2361*	-21.2533*	-21.2588*	-21.2360*	-21.2539*	-21.2587*
RLTGBRR	-21.2963*	-21.2997*	-21.3195*	-21.2959*	-21.2993v	-21.3192*
RONR5	-21.7170*	-21.7946*	-21.7402*	-21.7182*	-21.8026*	-21.7413*
R5YMR	-21.2289*	-21.2679*	-21.2524*	-21.2302*	-21.2679*	-21.2535*

Table (2-9) - Unit Root Test for the Residuals, Business Cycle 2 in Canada

(April 1992 to May 2009)

Variable	ADF			PP		
	Intercept	Intercept and Trend	None	Intercept	Intercept and Trend	None
RONR1	-31.1065*	-31.1570*	-31.1225*	-31.1064*	-31.1577*	-31.1225*
RPR	-31.0765*	-31.1310*	-31.0926*	-31.0764*	-31.1308*	-31.0926*
RONR2	-31.0474*	-31.1271*	-31.0635*	-31.0479*	-31.1325*	-31.0641*
R6MTBR	-31.6137*	-31.6302*	-31.6300*	-31.6139*	-31.6320*	-31.6302*
RONR3	-31.1657*	-31.1518*	-31.1818*	-31.1658*	-31.1518*	-31.1819*
R10YGBR	-31.1703*	-31.1939*	-31.1864*	-31.1703*	-31.1939*	-31.1864*
RONR4	-31.1652*	-31.1492*	-31.1813*	-31.1652*	-31.1492*	-31.1813*
RLTGBRR	-31.0626*	-31.0699*	-31.0787*	-31.0625*	-31.0698*	-31.0786*
RONR5	-31.0625*	-31.0467*	-31.0785*	-31.0631*	-31.0471*	-31.0792*
R5YMR	-31.2684*	-31.2729*	-31.2844*	-31.2835*	-31.2895*	-31.2998*

Table (2-10) - Unit Root Test for the Residuals, Business Cycle 3 in Canada

(May 2009 to November 2012)

Variable	ADF			PP		
	Intercept	Intercept and Trend	None	Intercept	Intercept and Trend	None
RONR1	-5.3668*	-5.4187*	-5.3744*	-16.4483*	-16.5323*	-16.4809*
RPR	-6.3004*	-6.3152*	-6.3173*	-13.7915	-13.7549*	-13.8187*
RONR2	-14.4488*	-14.4778*	-14.4829*	-14.4692*	-14.4851*	-14.5055*
R6MTBR	-14.8091*	-15.0029*	-14.8441*	-14.8091*	-14.9983*	-14.8441*
RONR3	-14.0049*	-14.0021*	-14.0378*	-14.0288*	-14.0341*	-14.0655*
R10YGBR	-14.6019*	-14.5887*	-14.6365*	-14.6020*	-14.5887*	-14.6366*
RONR4	-14.4790*	-14.4678*	-14.5129*	-14.5487*	-14.5403*	-14.5865*
RLTGBRR	-14.5906*	-14.5681*	-14.6253*	-14.5906*	-14.5681*	-14.6253*
RONR5	-14.1457*	-14.1467*	-14.1791*	-14.1902*	-14.2036*	-14.2276*
R5YMR	-14.4409*	-14.4855*	-14.4751*	-14.4404*	-14.4863*	-14.4747*

2.3.3 Nonlinear Granger Causality Test Results

The DP nonlinear Granger causality test results, including the amount of T-statistic and rejection probability at each lag length for the U.S. are reported in Tables (2-11) to (2-17) and for Canada are presented in Tables (2-18) to (2-20)[1]. Each table is related to one business cycle. For example, Table (2-11) shows that during business cycle 1 in the U.S., the null hypothesis that FFR does not Granger cause PR nonlinearly with $e = 1.5\sigma$ and $L_x = L_y = 6$ cannot be rejected but with the same lag length, we accept that PR Granger causes FFR nonlinearly at a 10% significance level.

Moreover, for each country, a summary of the nonlinear causality directions at the 5% significance level, are presented in Tables (2-21) and (2-22).[2]

[1]- In the Tables (2-11) to (2-20), *, *** and **** denote significance at the 1, 5 and 10 percent level, respectively.

[2]-To check the robustness of the obtained results, we also applied the tests for $e = 1\sigma$ and also for $e = n^{-0.3}$ ($e = Cn^{-\beta}$ where $C = 1$ and $\beta = 0.3$). The results did not change significantly and were almost the same as when $e = 1.5\sigma$. The test results for $e = 1\sigma$ are presented in Tables (2-11)' to (2-20)' of the Appendix.

Table (2-11) - Nonlinear Granger Causality Test Results, Business Cycle 1 in the U.S. ($e = 1.5$)

H0: FFR does not cause PR		H0: PR does not cause FFR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
-1.6030	0.9455	0.2600	0.3976	1
-0.1700	0.5674	0.6700	0.2515	2
0.0580	0.4768	1.3980	0.0811	3
0.1120	0.4555	1.0360	0.1501	4
-0.7250	0.7659	0.9050	0.1827	5
-0.3920	0.6525	1.4330	0.0760***	6
H0: FFR does not cause 6MTBR		H0: 6MTBR does not cause FFR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
0.1890	0.4249	0.8460	0.1987	1
0.5270	0.2992	0.9330	0.1754	2
0.8020	0.2112	1.2330	0.1088	3
0.7650	0.2221	0.9510	0.1708	4
1.0300	0.1515	0.9850	0.1623	5
0.9160	0.1799	0.5880	0.2783	6
H0: FFR does not cause 10YGBR		H0: 10YGBR does not cause FFR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
-0.5040	0.6930	0.3320	0.3701	1
1.1090	0.1337	1.1260	0.1302	2
1.0790	0.1403	0.8160	0.2074	3
1.4160	0.0783***	0.7880	0.2155	4
1.5910	0.0558***	0.4570	0.3239	5
1.5410	0.0616***	0.2200	0.4131	6
H0: FFR does not cause 30YMR		H0: 30YMR does not cause FFR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
0.1710	0.4322	-0.2670	0.6051	1
0.7970	0.2128	-0.5880	0.7218	2
0.2500	0.4013	-1.0780	0.8595	3
-0.6180	0.7318	-1.7210	0.9573	4
-0.0700	0.5281	-1.4440	0.9256	5
0.0870	0.4652	-1.5150	0.9351	6
H0: FFR does not cause BAACR		H0: BAACR does not cause FFR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
1.0380	0.1497	0.7360	0.2309	1
1.5060	0.0660***	0.9160	0.1797	2
1.6070	0.0540***	1.1580	0.1235	3
1.1370	0.1278	1.0360	0.1501	4
0.7420	0.2292	0.5010	0.3083	5
0.4850	0.3139	-0.5070	0.6938	6

Table (2-12) - Nonlinear Granger Causality Test Results, Business Cycle 2 in the U.S ($e = 1.5$)

H0: FFR does not cause PR		H0: PR does not cause FFR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
0.4220	0.3365	2.1530	0.0157**	1
1.2410	0.1073	2.0500	0.0202**	2
1.9650	0.0247**	2.1390	0.0162**	3
1.4540	0.0729***	1.8960	0.0290**	4
1.8150	0.0348**	1.9730	0.0243**	5
1.6830	0.0462**	2.3770	0.0087*	6
H0: FFR does not cause 6MTBR		H0: 6MTBR does not cause FFR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
1.9590	0.0251**	2.5370	0.0056*	1
0.5270	0.2992	0.9330	0.1754	2
2.5150	0.0060*	3.8380	0.0001*	3
2.0510	0.0201**	4.2540	0.0000*	4
1.9630	0.0248**	3.7590	0.0001*	5
1.6560	0.0489**	3.5310	0.0002*	6
H0: FFR does not cause 10YGBR		H0: 10YGBR does not cause FFR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
0.6150	0.2693	1.4240	0.0772***	1
0.4920	0.3114	1.6000	0.0548***	2
0.7420	0.2291	1.6280	0.0518***	3
0.6900	0.2452	1.9870	0.0235**	4
0.6710	0.2511	2.2830	0.0112**	5
0.8980	0.1846	2.0220	0.0216**	6
H0: FFR does not cause 30YMR		H0: 30YMR does not cause FFR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
2.1460	0.0160**	0.7230	0.2350	1
2.9940	0.0014*	0.4220	0.3365	2
2.9980	0.0014*	-0.0130	0.5052	3
2.7230	0.0032*	0.5120	0.3045	4
2.0270	0.0213**	0.9880	0.1615	5
1.1440	0.1263	0.6930	0.2441	6
H0: FFR does not cause BAACR		H0: BAACR does not cause FFR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
0.0610	0.4757	1.9260	0.0271**	1
-0.1810	0.5719	2.6160	0.0045*	2
0.1220	0.4515	2.4600	0.0069*	3
-0.1000	0.5400	2.6210	0.0044*	4
0.1650	0.4345	2.3720	0.0089*	5
0.7800	0.2178	1.9870	0.0235**	6

Table (2-13) - Nonlinear Granger Causality Test Results, Business Cycle 3 in the U.S. ($e = 1.5$)

H0: FFR does not cause PR		H0: PR does not cause FFR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
1.4440	0.0744***	2.1870	0.0144**	1
1.4130	0.0788***	2.0450	0.0205**	2
0.2560	0.3988	1.1880	0.1174	3
0.7770	0.2185	0.4600	0.3228	4
1.0610	0.1444	0.5640	0.2865	5
0.8530	0.1967	0.9690	0.1663	6
H0: FFR does not cause 6MTBR		H0: 6MTBR does not cause FFR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
0.1310	0.4478	0.4480	0.3272	1
0.2740	0.3922	0.3370	0.3682	2
1.2250	0.1103	1.1860	0.1178	3
1.4180	0.0781***	0.5030	0.3075	4
0.6320	0.2636	1.2260	0.1101	5
0.5230	0.3005	0.9130	0.1805	6
H0: FFR does not cause 10YGBR		H0: 10YGBR does not cause FFR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
1.4630	0.0718***	0.2270	0.4101	1
0.5360	0.2961	0.5630	0.2866	2
0.7780	0.2184	0.5000	0.3087	3
1.1350	0.1282	1.7910	0.0366**	4
0.6730	0.2504	1.2320	0.1091	5
1.1100	0.1335	0.4690	0.3194	6
H0: FFR does not cause 30YMR		H0: 30YMR does not cause FFR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
2.3770	0.0087*	0.9350	0.1749	1
2.3490	0.0094*	0.8320	0.2027	2
2.0490	0.0202**	0.7470	0.2276	3
1.7100	0.0436**	0.6600	0.2546	4
1.3520	0.0881***	-0.2590	0.6021	5
1.4570	0.0725***	-0.2370	0.5938	6
H0: FFR does not cause BAACR		H0: BAACR does not cause FFR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
-0.5150	0.6969	-1.3220	0.9070	1
1.3260	0.0924***	-1.0280	0.8481	2
0.4940	0.3107	-0.5820	0.7196	3
-0.1700	0.5674	0.4570	0.3237	4
0.0920	0.4635	0.1740	0.4308	5
0.0620	0.4752	0.4090	0.3413	6

Table (2-14) - Nonlinear Granger Causality Test Results, Business Cycle 4 in the U.S. ($e = 1.5$)

H0: FFR does not cause PR		H0: PR does not cause FFR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
3.4910	0.0002*	1.7570	0.0394**	1
3.2280	0.0006*	1.8610	0.0314**	2
2.4110	0.0080*	1.0200	0.1540	3
2.1450	0.0160**	1.7970	0.0362**	4
1.5110	0.0653***	1.4880	0.0683***	5
1.2980	0.0972***	0.8660	0.1933	6
H0: FFR does not cause 6MTBR		H0: 6MTBR does not cause FFR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
2.4680	0.0068*	0.5260	0.2994	1
3.4980	0.0002*	2.6280	0.0043*	2
2.6330	0.0042*	2.2140	0.0134**	3
2.2240	0.0131**	2.5990	0.0047*	4
2.0360	0.0209**	2.3810	0.0086*	5
1.5990	0.0549***	1.8670	0.0310**	6
H0: FFR does not cause 10YGBR		H0: 10YGBR does not cause FFR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
1.3740	0.0848***	0.6770	0.2492	1
3.5030	0.0002*	2.6220	0.0044*	2
3.6140	0.0002*	3.1200	0.0009*	3
3.1240	0.0009*	3.0390	0.0012*	4
3.0700	0.0011*	2.6960	0.0035*	5
2.7150	0.0033*	2.8200	0.0024*	6
H0: FFR does not cause 30YMR		H0: 30YMR does not cause FFR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
1.5590	0.0595***	0.4860	0.3135	1
0.4860	0.3135	0.5050	0.3067	2
0.2860	0.3874	0.0880	0.4649	3
-0.3480	0.6359	0.3310	0.3702	4
-1.2040	0.8857	0.1720	0.4317	5
-0.9180	0.8206	0.1140	0.4546	6
H0: FFR does not cause BAACR		H0: BAACR does not cause FFR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
2.1920	0.0142**	1.1800	0.1190	1
3.2750	0.0005*	3.0240	0.0013*	2
3.3080	0.0005*	2.7010	0.0035*	3
2.9070	0.0018*	2.3660	0.0090*	4
2.6770	0.0037*	2.1730	0.0149**	5
2.6630	0.0039*	1.8190	0.0344**	6

Table (2-15) - Nonlinear Granger Causality Test Results, Business Cycle 5 in the U.S. ($e = 1.5$)

H0: FFR does not cause PR		H0: PR does not cause FFR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
1.8460	0.0324**	1.4780	0.0697***	1
1.4970	0.0673***	1.2470	0.1062	2
0.9090	0.1818	1.2070	0.1137	3
0.5110	0.3048	0.9790	0.1639	4
0.4120	0.3403	1.0590	0.1449	5
-0.0540	0.5217	0.9390	0.1740	6
H0: FFR does not cause 6MTBR		H0: 6MTBR does not cause FFR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
2.1860	0.0144**	3.2510	0.0006*	1
2.0080	0.0223**	3.8950	0.0001*	2
1.4510	0.0734***	3.2920	0.0005*	3
1.5540	0.0601***	3.6840	0.0001*	4
1.5720	0.0580***	3.2570	0.0006*	5
0.9750	0.1647	3.0180	0.0013*	6
H0: FFR does not cause 10YGBR		H0: 10YGBR does not cause FFR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
-0.1740	0.5691	-0.2590	0.6020	1
-0.4500	0.6737	1.1990	0.1153	2
-0.0110	0.5044	1.0160	0.1549	3
0.0690	0.4726	1.3820	0.0835***	4
1.0280	0.1521	1.1390	0.1274	5
0.3140	0.3768	1.5720	0.0580***	6
H0: FFR does not cause 30YMR		H0: 30YMR does not cause FFR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
-0.3110	0.6222	0.4480	0.3269	1
0.9670	0.1667	1.6640	0.0480**	2
0.4140	0.3395	1.6900	0.0455**	3
0.7790	0.2180	2.2260	0.0130**	4
1.2640	0.1031	1.7330	0.0415**	5
0.7860	0.2160	1.3450	0.0893***	6
H0: FFR does not cause BAACR		H0: BAACR does not cause FFR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
0.0700	0.4722	-0.2710	0.6067	1
0.1180	0.4530	0.7100	0.2388	2
-0.6140	0.7303	0.7410	0.2294	3
-0.9610	0.8318	1.3620	0.0866***	4
0.2010	0.4205	1.2360	0.1082	5
0.2080	0.4175	0.5720	0.2838	6

Table (2-16) - Nonlinear Granger Causality Test Results, Business Cycle 6 in the U.S. ($e = 1.5$)

H0: FFR does not cause PR		H0: PR does not cause FFR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
2.0580	0.0198**	0.8060	0.2102	1
2.6170	0.0044*	1.4560	0.0727***	2
2.2570	0.0120**	1.6220	0.0524***	3
1.4430	0.0745***	0.9210	0.1786	4
1.3130	0.0946***	1.2930	0.0980***	5
0.7430	0.2287	1.1070	0.1341	6
H0: FFR does not cause 6MTBR		H0: 6MTBR does not cause FFR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
2.0950	0.0181**	1.8730	0.0305**	1
1.9430	0.0260**	2.6720	0.0038*	2
1.3610	0.0868***	2.4530	0.0071*	3
0.7930	0.2139	1.9000	0.0287**	4
0.4010	0.3443	1.5030	0.0664***	5
0.3760	0.3536	1.9070	0.0283**	6
H0: FFR does not cause 10YGBR		H0: 10YGBR does not cause FFR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
-0.5860	0.7209	0.0630	0.4750	1
-0.6190	0.7320	0.9270	0.1770	2
0.0080	0.4969	1.6460	0.0498**	3
0.3440	0.3653	0.6380	0.2617	4
0.2850	0.3877	0.9660	0.1670	5
1.1460	0.1259	0.0750	0.4702	6
H0: FFR does not cause 30YMR		H0: 30YMR does not cause FFR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
-0.5190	0.6983	-0.9590	0.8311	1
-1.1190	0.8684	-1.3220	0.9069	2
-1.3090	0.9048	-0.8550	0.8036	3
-1.0760	0.8590	-0.4470	0.6727	4
-0.9670	0.8333	-0.4380	0.6693	5
-0.6300	0.7356	-0.1160	0.5462	6
H0: FFR does not cause BAACR		H0: BAACR does not cause FFR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
-1.3840	0.9168	-1.1100	0.8666	1
-1.0630	0.8562	-0.8980	0.8154	2
-0.8500	0.8022	-0.1030	0.5410	3
-0.4950	0.6896	0.3720	0.3549	4
-0.7830	0.7832	0.6510	0.2575	5
-0.7360	0.7692	-0.4290	0.6661	6

Table (2-17) - Nonlinear Granger Causality Test Results, Business Cycle 7 in the U.S. ($e = 1.5$)

H0: FFR does not cause PR		H0: PR does not cause FFR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
1.1440	0.1264	2.2610	0.0119**	1
2.3740	0.0088*	2.4130	0.0079*	2
1.2620	0.1035	2.1350	0.0164**	3
1.7230	0.0425**	2.1760	0.0148**	4
1.4530	0.0731***	2.0720	0.0191**	5
1.0330	0.1508	1.8280	0.0338**	6
H0: FFR does not cause 6MTBR		**H0: 6MTBR does not cause FFR**		**Lx=Ly**
T- Statistics	Probability	T- Statistics	Probability	
2.4540	0.0071*	2.9100	0.0018*	1
2.1240	0.0169**	2.2180	0.0133**	2
2.5660	0.0051*	2.0280	0.0213**	3
2.0210	0.0216**	1.7880	0.0369**	4
1.9050	0.0284**	2.1490	0.0158**	5
1.4690	0.0709***	1.4930	0.0677***	6
H0: FFR does not cause 10YGBR		**H0: 10YGBR does not cause FFR**		**Lx=Ly**
T- Statistics	Probability	T- Statistics	Probability	
1.7350	0.0413**	0.8820	0.1888	1
2.3880	0.0085*	-0.8320	0.7973	2
2.0470	0.0203**	-0.4480	0.6729	3
1.2430	0.1069	-1.8060	0.9646	4
0.7780	0.2183	-0.1560	0.5620	5
1.2770	0.1007	-0.9900	0.8390	6
H0: FFR does not cause 30YMR		**H0: 30YMR does not cause FFR**		**Lx=Ly**
T- Statistics	Probability	T- Statistics	Probability	
1.2840	0.0996***	1.0660	0.1433	1
2.1700	0.0150**	2.9300	0.0017*	2
2.1470	0.0159**	2.0760	0.0189**	3
1.9570	0.0252**	1.6560	0.0488**	4
2.1000	0.0179**	1.5200	0.0643***	5
1.7660	0.0387**	1.5300	0.0630***	6
H0: FFR does not cause BAACR		**H0: BAACR does not cause FFR**		**Lx=Ly**
T- Statistics	Probability	T- Statistics	Probability	
0.2690	0.3940	1.0020	0.1582	1
2.4120	0.0079*	0.5350	0.2964	2
1.2730	0.1015	1.4180	0.0781***	3
0.4920	0.3112	0.8020	0.2112	4
0.3930	0.3471	1.3130	0.0947***	5
0.8120	0.2083	0.8920	0.1863	6

Table (2-18) - Nonlinear Granger Causality Test Results, Business Cycle 1 in Canada ($e = 1.5$)

H0: ONR does not cause PR		H0: PR does not cause ONR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
2.710	0.00337*	3.215	0.00065*	1
3.058	0.00111*	3.933	0.00004*	2
3.812	0.00007*	3.777	0.00008*	3
2.929	0.00170*	3.984	0.00003*	4
2.037	0.02083**	3.509	0.00022*	5
1.948	0.02572**	3.183	0.00073*	6
H0: ONR does not cause 6MTBR		H0: 6MTBR does not cause ONR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
2.035	0.02092**	2.826	0.00236*	1
2.207	0.01365**	4.163	0.00002*	2
2.220	0.01321**	4.654	0.00000*	3
1.796	0.03624**	4.034	0.00003*	4
1.803	0.03572**	3.582	0.00017*	5
2.099	0.01792**	3.285	0.00051*	6
H0: ONR does not cause 10YGBR		H0: 10YGBR does not cause ONR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
0.195	0.42274	2.205	0.01374**	1
0.818	0.20654	2.152	0.01570**	2
0.278	0.39055	1.535	0.06234***	3
0.638	0.26178	1.956	0.02526**	4
0.138	0.44520	2.193	0.01414**	5
0.999	0.15884	2.246	0.01236**	6
H0: ONR does not cause LTGBR		H0: LTGBRR does not cause ONR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
1.878	0.03020**	3.395	0.00034*	1
2.704	0.00343*	4.600	0.00000*	2
2.640	0.00415*	4.097	0.00002*	3
2.917	0.00177*	3.859	0.00006*	4
2.368	0.00894*	3.959	0.00004*	5
2.263	0.01181**	3.398	0.00034*	6
H0: ONR does not cause 5YMR		H0: 5YMR does not cause ONR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
1.110	0.13353	1.633	0.05121***	1
1.968	0.02453**	1.968	0.02452**	2
2.675	0.00374*	3.069	0.00108*	3
1.990	0.02332**	2.600	0.00467*	4
2.261	0.01189**	2.201	0.01388**	5
2.059	0.01974**	2.043	0.02050**	6

Table (2-19) - Nonlinear Granger Causality Test Results, Business Cycle 2 in Canada ($e = 1.5$)

H0: ONR does not cause PR		H0: PR does not cause ONR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
3.674	0.00012*	3.033	0.00121*	1
3.564	0.00018*	4.226	0.00001*	2
4.504	0.00000*	4.420	0.00000*	3
4.137	0.00002*	4.249	0.00001*	4
3.710	0.00010*	4.155	0.00002*	5
3.691	0.00011*	3.516	0.00022*	6
H0: ONR does not cause 6MTBR		H0: 6MTBR does not cause ONR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
3.658	0.00013*	2.379	0.00867*	1
4.224	0.00001*	4.045	0.00003*	2
5.015	0.00000*	4.238	0.00001*	3
4.354	0.00001*	4.416	0.00001*	4
3.943	0.00004*	4.121	0.00002*	5
3.878	0.00005*	3.640	0.00014*	6
H0: ONR does not cause 10YGBR		H0: 10YGBR does not cause ONR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
3.674	0.00012*	3.033	0.00121*	1
3.564	0.00018*	4.226	0.00001*	2
4.504	0.00000*	4.420	0.00000*	3
4.137	0.00002*	4.249	0.00001*	4
3.710	0.00010*	4.155	0.00002*	5
3.691	0.00011*	3.516	0.00022*	6
H0: ONR does not cause LTGBR		H0: LTGBRR does not cause ONR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
3.658	0.00013*	2.379	0.00867*	1
4.224	0.00001*	4.045	0.00003*	2
5.015	0.00000*	4.238	0.00001*	3
4.354	0.00001*	4.416	0.00001*	4
3.943	0.00004*	4.121	0.00002*	5
3.878	0.00005*	3.640	0.00014*	6
H0: ONR does not cause 5YMR		H0: 5YMR does not cause ONR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
1.491	0.06792***	1.041	0.14893	1
2.148	0.01584**	2.168	0.01507**	2
1.732	0.04161**	1.899	0.02878**	3
1.938	0.02631**	1.951	0.02553**	4
1.697	0.04483**	2.139	0.01623**	5
0.868	0.19279	1.983	0.02368**	6

Table (2-20) - Nonlinear Granger Causality Test Results, Business Cycle 3 in Canada ($e = 1.5$)

H0: ONR does not cause PR		H0: PR does not cause ONR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
2.568	0.00511*	2.757	0.00292*	1
2.870	0.00205*	3.126	0.00089*	2
2.645	0.00409*	3.089	0.00100*	3
1.770	0.03840**	2.748	0.00300*	4
2.277	0.01139**	2.670	0.00379*	5
1.946	0.02584**	2.198	0.01396**	6
H0: ONR does not cause 6MTBR		H0: 6MTBR does not cause ONR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
1.603	0.05447***	2.839	0.00226*	1
1.463	0.07177***	3.239	0.00060*	2
1.698	0.04472**	3.091	0.00100*	3
1.701	0.04445**	2.974	0.00147*	4
2.049	0.02021**	2.797	0.00258*	5
0.974	0.16508	2.094	0.01814**	6
H0: ONR does not cause 10YGBR		H0: 10YGBR does not cause ONR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
0.743	0.22862	1.140	0.12718	1
1.440	0.07493***	1.472	0.07056***	2
1.671	0.04737**	1.337	0.09065***	3
1.592	0.05567***	1.788	0.03689**	4
1.021	0.15359	1.941	0.02615**	5
1.393	0.08176***	1.588	0.05615***	6
H0: ONR does not cause LTGBR		H0: LTGBRR does not cause ONR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
0.268	0.39422	0.661	0.25420	1
0.939	0.17396	0.934	0.17507	2
0.887	0.18749	0.447	0.32757	3
0.999	0.15895	0.708	0.23937	4
1.012	0.15585	0.756	0.22481	5
0.864	0.19385	-0.118	0.54686	6
H0: ONR does not cause 5YMR		H0: 5YMR does not cause ONR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
0.205	0.41896	1.923	0.02726**	1
0.852	0.19711	2.081	0.01873**	2
1.030	0.15152	1.438	0.07527***	3
1.308	0.09538***	0.938	0.17410	4
0.827	0.20406	0.635	0.26275	5
0.780	0.21772	0.214	0.41543	6

Table (2-21) - Nonlinear Granger Causality Directions
during the Last Seven Business Cycles in the U.S.

Business Cycle 1	**Business Cycle 2**	**Business Cycle 3**	**Business Cycle 4**	**Business Cycle 5**	**Business Cycle 6**	**Business Cycle 7**
$\text{FFR} \overset{\text{NL}}{\nleftrightarrow} \text{PR}$	$\text{FFR} \overset{\text{NL}}{\leftrightarrow} \text{PR}$	$\text{FFR} \overset{\text{NL}}{\leftarrow} \text{PR}$	$\text{FFR} \overset{\text{NL}}{\leftrightarrow} \text{PR}$	$\text{FFR} \overset{\text{NL}}{\rightarrow} \text{PR}$	$\text{FFR} \overset{\text{NL}}{\rightarrow} \text{PR}$	$\text{FFR} \overset{\text{NL}}{\leftrightarrow} \text{PR}$
$\text{FFR} \overset{\text{NL}}{\nleftrightarrow} \text{6MTBR}$	$\text{FFR} \overset{\text{NL}}{\leftrightarrow} \text{6MTBR}$	$\text{FFR} \overset{\text{NL}}{\nleftrightarrow} \text{6MTBR}$	$\text{FFR} \overset{\text{NL}}{\leftrightarrow} \text{6MTBR}$	$\text{FFR} \overset{\text{NL}}{\leftrightarrow} \text{6MTBR}$	$\text{FFR} \overset{\text{NL}}{\leftrightarrow} \text{6MTBR}$	$\text{FFR} \overset{\text{NL}}{\leftrightarrow} \text{6MTBR}$
$\text{FFR} \overset{\text{NL}}{\nleftrightarrow} \text{10YGBR}$	$\text{FFR} \overset{\text{NL}}{\leftarrow} \text{10YGBR}$	$\text{FFR} \overset{\text{NL}}{\leftarrow} \text{10YGBR}$	$\text{FFR} \overset{\text{NL}}{\leftrightarrow} \text{10YGBR}$	$\text{FFR} \overset{\text{NL}}{\nleftrightarrow} \text{10YGBR}$	$\text{FFR} \overset{\text{NL}}{\leftarrow} \text{10YGBR}$	$\text{FFR} \overset{\text{NL}}{\rightarrow} \text{10YGBR}$
$\text{FFR} \overset{\text{NL}}{\nleftrightarrow} \text{30YMR}$	$\text{FFR} \overset{\text{NL}}{\rightarrow} \text{30YMY}$	$\text{FFR} \overset{\text{NL}}{\rightarrow} \text{30YMR}$	$\text{FFR} \overset{\text{NL}}{\nleftrightarrow} \text{30YMR}$	$\text{FFR} \overset{\text{NL}}{\leftarrow} \text{30YMR}$	$\text{FFR} \overset{\text{NL}}{\nleftrightarrow} \text{30YMR}$	$\text{FFR} \overset{\text{NL}}{\leftrightarrow} \text{30YMR}$
$\text{FFR} \overset{\text{NL}}{\nleftrightarrow} \text{BAACR}$	$\text{FFR} \overset{\text{NL}}{\leftarrow} \text{BAACR}$	$\text{FFR} \overset{\text{NL}}{\nleftrightarrow} \text{BAACR}$	$\text{FFR} \overset{\text{NL}}{\leftrightarrow} \text{BAACR}$	$\text{FFR} \overset{\text{NL}}{\nleftrightarrow} \text{BAACR}$	$\text{FFR} \overset{\text{NL}}{\nleftrightarrow} \text{BAACR}$	$\text{FFR} \overset{\text{NL}}{\rightarrow} \text{BAACR}$

Note: The arrows imply the direction of "Nonlinear" (NL) Granger causality which runs between series.

Table (2-22) - Nonlinear Granger Causality Directions
during the Last Three Business Cycles in Canada

Business Cycle 1	**Business Cycle 2**	**Business Cycle 3**
$\text{ONR} \overset{\text{NL}}{\leftrightarrow} \text{PR}$	$\text{ONR} \overset{\text{NL}}{\leftrightarrow} \text{PR}$	$\text{ONR} \overset{\text{NL}}{\leftrightarrow} \text{PR}$
$\text{ONR} \overset{\text{NL}}{\leftrightarrow} \text{6MTBR}$	$\text{ONR} \overset{\text{NL}}{\leftrightarrow} \text{6MTBR}$	$\text{ONR} \overset{\text{NL}}{\leftrightarrow} \text{6MTBR}$
$\text{ONR} \overset{\text{NL}}{\leftarrow} \text{10YGBR}$	$\text{ONR} \overset{\text{NL}}{\leftrightarrow} \text{10YGBR}$	$\text{ONR} \overset{\text{NL}}{\leftrightarrow} \text{10YGBR}$
$\text{ONR} \overset{\text{NL}}{\leftrightarrow} \text{LTGBR}$	$\text{ONR} \overset{\text{NL}}{\leftrightarrow} \text{LTGBR}$	$\text{ONR} \overset{\text{NL}}{\nleftrightarrow} \text{LTGBR}$
$\text{ONR} \overset{\text{NL}}{\leftrightarrow} \text{5YMR}$	$\text{ONR} \overset{\text{NL}}{\leftrightarrow} \text{5YMR}$	$\text{ONR} \overset{\text{NL}}{\leftarrow} \text{5YMR}$

The results for the U.S. show that there is a bidirectional nonlinear causality between PR and FFR in business cycles 2, 4 and 7. While during cycles 5 and 6 the nonlinear causality runs from FFR to PR, in cycle 3 it runs in the opposite direction. In business cycle 1, there is not any significant causality direction between these two interest rates.

The results also show that there is a two-way causality between 6MTBR and FFR except for cycles 1 and 3 that there is no nonlinear causality between 6MTBR and FFR.

It can be seen that while during business cycles 2, 3 and 6, the causality runs from 10YGBR to FFR, in cycles 7, it runs in the opposite direction. Also, we can see that in cycles 1 and 5, there is not significant nonlinear causality between these interest rates.

FFR, nonlinearly, Granger causes 30YMR in business cycles 2, 3 and 7, and 30YMR causes FFR in cycles 5 and 7; but during cycles 1, 4 and 6, they do not cause each other.

There is a significant nonlinear Granger causality from FFR to BAACR in cycles 4 and 7. There is also a significant nonlinear causality in the opposite direction during cycles 2 and 4. In the rest of business cycles meaning cycles 1, 3, 5 and 6, none of these interest rates nonlinearly causes each other.

The results for Canada show that, during the last three business cycles, there is a bidirectional nonlinear Granger causality between ONR and two short-term interest rates of PR and 6MTBR. Moreover, it can be seen that during cycles 1 and 2, there is a two-way causality between ONR and three long-term interest rates of 10YGBR, LTGBR and 5YMR, except in cycle 1 that there is a one-way causality from 10YGBR to ONR. However, in the last business cycle, there is not any nonlinear Granger causality direction between ONR with LTGBR and there is a unidirectional causality from 5YMR to ONR.

2.4 Combining the Linear and Nonlinear Granger Causality Directions

According to the obtained results, there are significant nonlinear Granger causality relationships between the federal funds rate (in the U.S.) and overnight rate (in Canada) with other interest rates in some periods. Also, when comparing these results with those achieved in the previous chapter, it shows that there are some cases where we could not find significant linear causality relationships between interest rates whereas, we were able to detect evidence of nonlinear causality between them.

From the linear Granger causality relationships that are obtained in the first chapter[1] and the nonlinear ones which are presented in Tables (2-21) and (2-22) of this chapter, the total (linear and nonlinear) Granger causality directions between short-term and long-term interest rates can be derived.

For example, Table (1-21) in the previous chapter shows that during business cycle 4 in the U.S., there is a one-way linear Granger causality direction from 30YMR to FFR. According to Table (2-21) of the current chapter, in the same cycle, there is a unidirectional nonlinear Granger causality direction from FFR to 30YMR. Therefore, we can say that these two interest rates Granger cause each other, one linearly and the other nonlinearly.

As another example, consider Table (1-22) of the first chapter which shows that during business cycle 1 in Canada, there is a one-way linear Granger causality that runs from 6MTBR to ONR. Based upon Table (2-22) of this chapter, there is a bidirectional nonlinear Granger causality between ONR and 6MTBR. Hence, one can conclude that these two rates Granger cause each other. With the same logic, we derive Tables (2-23) and (2-24) for the U.S. and Canada respectively.

It can be seen that in the case of the U.S., except in cycle 3 that FFR does not Granger cause 6MTBR and 10YGBR, and also in cycle 5 that it does not Granger cause 30YMR significantly; in all the other periods and cases, FFR Granger causes four various interest rates of our sample meaning PR, 6MTBR, 10YGBR and 30YMR. FFR Granger causes BAACR during business cycles 5 and 7. In cycles 2, 3 and 4 there is a unidirectional causality from BAACR to FFR.

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[1]- See tables (1-21) and (1-22) of the last chapter.

Table (2-23) - Linear and Nonlinear Granger Causality Directions
during the Last Seven Business Cycles in the U.S.

Business Cycle 1	**Business Cycle 2**	**Business Cycle 3**	**Business Cycle 4**	**Business Cycle 5**	**Business Cycle 6**	**Business Cycle 7**
$\mathrm{FFR} \overset{\substack{\text{L NL}\\ \rightarrow,\nleftrightarrow}}{\Longrightarrow} \mathrm{PR}$	$\mathrm{FFR} \overset{\substack{\text{L NL}\\ \leftrightarrow,\leftrightarrow}}{\Longleftrightarrow} \mathrm{PR}$	$\mathrm{FFR} \overset{\substack{\text{L NL}\\ \rightarrow,\leftarrow}}{\Longleftrightarrow} \mathrm{PR}$	$\mathrm{FFR} \overset{\substack{\text{L NL}\\ \rightarrow,\leftrightarrow}}{\Longleftrightarrow} \mathrm{PR}$	$\mathrm{FFR} \overset{\substack{\text{L NL}\\ \leftrightarrow,\rightarrow}}{\Longleftrightarrow} \mathrm{PR}$	$\mathrm{FFR} \overset{\substack{\text{L NL}\\ \leftrightarrow,\rightarrow}}{\Longleftrightarrow} \mathrm{PR}$	$\mathrm{FFR} \overset{\substack{\text{L NL}\\ \leftrightarrow,\leftrightarrow}}{\Longleftrightarrow} \mathrm{PR}$
$\mathrm{FFR} \overset{\substack{\text{L NL}\\ \leftrightarrow,\nleftrightarrow}}{\Longleftrightarrow} \mathrm{6MTBR}$	$\mathrm{FFR} \overset{\substack{\text{L NL}\\ \leftrightarrow,\leftrightarrow}}{\Longleftrightarrow} \mathrm{6MTBR}$	$\mathrm{FFR} \overset{\substack{\text{L NL}\\ \leftarrow,\nleftrightarrow}}{\Longleftarrow} \mathrm{6MTBR}$	$\mathrm{FFR} \overset{\substack{\text{L NL}\\ \leftrightarrow,\leftrightarrow}}{\Longleftrightarrow} \mathrm{6MTBR}$	$\mathrm{FFR} \overset{\substack{\text{L NL}\\ \leftarrow,\leftrightarrow}}{\Longleftrightarrow} \mathrm{6MTBR}$	$\mathrm{FFR} \overset{\substack{\text{L NL}\\ \leftrightarrow,\leftrightarrow}}{\Longleftrightarrow} \mathrm{6MTBR}$	$\mathrm{FFR} \overset{\substack{\text{L NL}\\ \leftrightarrow,\leftrightarrow}}{\Longleftrightarrow} \mathrm{6MTBR}$
$\mathrm{FFR} \overset{\substack{\text{L NL}\\ \rightarrow,\nleftrightarrow}}{\Longrightarrow} \mathrm{10YGBR}$	$\mathrm{FFR} \overset{\substack{\text{L NL}\\ \leftrightarrow,\leftarrow}}{\Longleftrightarrow} \mathrm{10YGBR}$	$\mathrm{FFR} \overset{\substack{\text{L NL}\\ \leftarrow,\leftarrow}}{\Longleftarrow} \mathrm{10YGBR}$	$\mathrm{FFR} \overset{\substack{\text{L NL}\\ \leftarrow,\leftrightarrow}}{\Longleftrightarrow} \mathrm{10YGBR}$	$\mathrm{FFR} \overset{\substack{\text{L NL}\\ \leftrightarrow,\nleftrightarrow}}{\Longleftrightarrow} \mathrm{10YGBR}$	$\mathrm{FFR} \overset{\substack{\text{L NL}\\ \leftrightarrow,\leftarrow}}{\Longleftrightarrow} \mathrm{10YGBR}$	$\mathrm{FFR} \overset{\substack{\text{L NL}\\ \rightarrow,\rightarrow}}{\Longrightarrow} \mathrm{10YGBR}$
$\mathrm{FFR} \overset{\substack{\text{L NL}\\ \rightarrow,\nleftrightarrow}}{\Longrightarrow} \mathrm{30YMR}$	$\mathrm{FFR} \overset{\substack{\text{L NL}\\ \leftrightarrow,\rightarrow}}{\Longleftrightarrow} \mathrm{30YMR}$	$\mathrm{FFR} \overset{\substack{\text{L NL}\\ \rightarrow,\rightarrow}}{\Longrightarrow} \mathrm{30YMR}$	$\mathrm{FFR} \overset{\substack{\text{L NL}\\ \leftarrow,\nleftrightarrow}}{\Longleftrightarrow} \mathrm{30YMR}$	$\mathrm{FFR} \overset{\substack{\text{L NL}\\ \leftarrow,\leftarrow}}{\Longleftarrow} \mathrm{30YMR}$	$\mathrm{FFR} \overset{\substack{\text{L NL}\\ \rightarrow,\nleftrightarrow}}{\Longrightarrow} \mathrm{30YMR}$	$\mathrm{FFR} \overset{\substack{\text{L NL}\\ \rightarrow,\leftrightarrow}}{\Longleftrightarrow} \mathrm{30YMR}$
$\mathrm{FFR} \overset{\substack{\text{L NL}\\ \nleftrightarrow,\nleftrightarrow}}{\not\Longleftrightarrow} \mathrm{BAACR}$	$\mathrm{FFR} \overset{\substack{\text{L NL}\\ \leftarrow,\leftarrow}}{\Longleftarrow} \mathrm{BAACR}$	$\mathrm{FFR} \overset{\substack{\text{L NL}\\ \leftarrow,\nleftrightarrow}}{\Longleftarrow} \mathrm{BAACR}$	$\mathrm{FFR} \overset{\substack{\text{L NL}\\ \leftarrow,\leftrightarrow}}{\Longleftarrow} \mathrm{BAACR}$	$\mathrm{FFR} \overset{\substack{\text{L NL}\\ \rightarrow,\nleftrightarrow}}{\Longrightarrow} \mathrm{BAACR}$	$\mathrm{FFR} \overset{\substack{\text{L NL}\\ \nleftrightarrow,\nleftrightarrow}}{\not\Longleftrightarrow} \mathrm{BAACR}$	$\mathrm{FFR} \overset{\substack{\text{L NL}\\ \leftarrow,\rightarrow}}{\Longleftrightarrow} \mathrm{BAACR}$

Note: The thin arrows imply the direction of "Linear" (L) or "Nonlinear" (NL) Granger causalities. The bold arrows show the total (linear and nonlinear) Granger causality which runs between the series.

Table (2-24) - Linear and Nonlinear Granger Causality Directions during the Last Seven Business Cycles in the U.S.

Business Cycle 1	**Business Cycle 2**	**Business Cycle 3**
$ONR \overset{\overset{L\ \ NL}{\leftrightarrow,\leftrightarrow}}{\Longleftrightarrow} PR$	$ONR \overset{\overset{L\ \ NL}{\leftrightarrow,\leftrightarrow}}{\Longleftrightarrow} PR$	$ONR \overset{\overset{L\ \ NL}{\leftrightarrow,\leftrightarrow}}{\Longleftrightarrow} PR$
$ONR \overset{\overset{L\ \ NL}{\leftarrow,\leftrightarrow}}{\Longleftrightarrow} 6MTBR$	$ONR \overset{\overset{L\ \ NL}{\leftrightarrow,\leftrightarrow}}{\Longleftrightarrow} 6MTBR$	$ONR \overset{\overset{L\ \ NL}{\leftarrow,\leftrightarrow}}{\Longleftrightarrow} 6MTBR$
$ONR \overset{\overset{L\ \ NL}{\leftarrow,\leftarrow}}{\Longleftarrow} 10YGBR$	$ONR \overset{\overset{L\ \ NL}{\leftrightarrow,\leftrightarrow}}{\Longleftrightarrow} 10YGBR$	$ONR \overset{\overset{L\ \ NL}{\nleftrightarrow,\leftrightarrow}}{\Longleftrightarrow} 10YGBR$
$ONR \overset{\overset{L\ \ NL}{\leftrightarrow,\leftrightarrow}}{\Longleftrightarrow} LTGBR$	$ONR \overset{\overset{L\ \ NL}{\leftrightarrow,\leftrightarrow}}{\Longleftrightarrow} LTGBR$	$ONR \overset{\overset{L\ \ NL}{\rightarrow,\nleftrightarrow}}{\Longrightarrow} LTGBR$
$ONR \overset{\overset{L\ \ NL}{\leftrightarrow,\leftrightarrow}}{\Longleftrightarrow} 5YMR$	$ONR \overset{\overset{L\ \ NL}{\leftrightarrow,\leftrightarrow}}{\Longleftrightarrow} 5YMR$	$ONR \overset{\overset{L\ \ NL}{\leftrightarrow,\leftarrow}}{\Longleftrightarrow} 5YMR$

In the case of Canada, it can be observed that except in cycle 1 that there is a unidirectional causality from 10YGBR to ONR and in cycle 3 that there is a one-way causality from ONR to LTGBR; in all the other cases during the last three business cycles, there is a two-way Granger causality.

Therefore, according to our results, we can see that during the related periods in the U.S. and Canada, the most common Granger causality direction between FFR and ONR with other interest rates is a bidirectional one.

2.5 Comparing with Pollin (2008)

The differences between Pollin's experimental work and the current study can be summarized as follows:

Difference in the Data

Pollin (2008) applied monthly data while we used weekly data. Also, the experimental period for Pollin's work was the last five business cycles in the U.S. up to 2008 (November 1973 to February 2008); while we applied our tests for the last seven business cycles (December 1969 to May 2012) in the U.S. and also the last three business cycles (June 1981 to November 2012) in Canada.

Difference in the Approach

To find the linear Granger causality test, Pollin (2008), applied a simple VAR model; while we used the Toda-Yamamoto (TY) approach.

Before applying the simple VAR model to exert the linear Granger causality test, Pollin converted the variables into the first differenced form to make them stationary; whereas, in this thesis, because of applying the Toda-Yamamoto (TY) approach, we could exert the linear Granger causality test for the variables in the level form even if they were non-stationary.

In estimating VAR models to find the linear Granger causality relationships between interest rates, Pollin did not choose the optimum lag lengths according to the related criteria. Instead, he set the lag lengths for all of the VAR models equals to 12, while in the first chapter of this thesis, these criteria were used to find the best lag length for estimating each VAR model.

Unlike this study, Pollin's paper did not point to any robustness check for the estimations.

Pollin put his conclusions about the causal relationships between the federal funds rate and the market interest rates based on the linear Granger causality test; while interest rates may also Granger causes each other nonlinearly and these causality effects cannot be detected by linear Granger causality test. Therefore, in the current chapter, we also applied nonlinear Granger causality test that gives us some extra information relative to the linear Granger causality test.

Difference in the Results and Conclusions

As was explained in the "Literature Review" section of the previous chapter, Pollin, as a post-Keynesian structuralist, believes that recently, the federal funds rate cannot cause long-term interest rates significantly; and, the significant two-way Granger causality between FFR and these interest rates have been diminished in recent business cycles. Therefore, according to his belief, the central banks' power to exogenously determine the market rates (except the prime rate) is limited; whereas, after combining the linear and nonlinear Granger causality test results, our findings show that during recent periods, FFR and ONR Granger causes other interest rates significantly. We also concluded that two-way total (linear and nonlinear) Granger causality is the most common Granger causality direction between short-term and long-term interest rates.

Even about the linear Granger causality, our findings in the first chapter are not the same as Pollin's ones. According to the linear Granger causality test results in Pollin's paper, two-way linear Granger causality direction is the most causality direction between FFR and other interest rates; whereas, we did not drive this conclusion about the linear Granger causality for the U.S. Moreover, unlike Pollin's study, the first chapter results showed that FFR and ONR, in the U.S. and in Canada respectively, linearly Granger causes most of the market interest rates significantly.

Difference in the interpretation

Pollin's paper showed that there is a bidirectional causality between FFR and market rates (except the prime rate); adding that in the most recent period there is only a one-way causality going from long-term interest rates to FFR. He claimed that such results are obtained because the Federal Reserve's power to determine interest rates exogenously is limited and *"... most market rates are determined with a high degree of endogeneity as an outcome of financial market operations."* (Pollin, 2008, p.5) In other words, as a post-Keynesian structuralist, Pollin believes that long-term interest rates are determined endogenously in the financial markets, and are not influenced by the Federal Reserve, while the market rates cause the federal funds rate, rather than vice versa. In our study we show instead that there are two-way Granger causality relationships between the federal funds rate and the overnight rate on one hand, and all market interest rates on the other hand.

We believe that the causality direction that runs from FFR and ONR to the long-term interest rates is due to the fact that FFR and ONR, as the exogenous variables, linearly or nonlinearly, help to predict long-term interest rates significantly.

The opposite direction causality that goes from long-term interest rates to FFR and ONR can be explained by the expectation theory or the liquidity preferences theory. According to the expectation theory, long-term interest rate (LR) can be obtained as follows:

$$LR_0 \approx \sum_{t=0}^{T} E(SR_t) \quad (11)$$

where SR_t shows short-term interest rate at time t and E denotes the expectation. Therefore, current long-term interest rates embody future short-term interest rates which are administered by the monetary authorities; and as a result, statistical tests show significant causality effect that runs from long-term interest rate to the short-term interest rate.[1]

According to the liquidity preference theory[2], the long-term interest rate reflects liquidity preference concerns. This property of the long-term interest rate will help to predict future values of short-term interest rates, so Granger causes it. For example, during recession periods, most notably during the Great Recession, because of the lack of confidence in the economic situation and fears of the future, people did not want to hold potentially illiquid long-term bonds. Therefore, the price of bonds went down and long-term interest rates went up. Thus, in an attempt to stabilize the economy, the Central Bank did react by decreasing short-term interest rates. In other words, even if long-term rates cause short-term rates, this does not mean that markets are forcing the central bank to go in the same direction.

Calculating the correlation coefficients for the financial crisis, at least at the beginning, confirms the above statements. For instance, calculated correlation coefficient between FFR

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[1]- This interpretation was expressed for the first time, by two post-Keynesian economists, Moore (1991) and Palley (1991).

[2]- Liquidity preference theory was first put forward by Keynes (1936).

and 10YGBR for the period of January 2008 to December 2008 (during the beginning of the recent financial crisis) is negative and equal to -0.40.

2.6 Summary and Conclusion

In the previous chapter, we adopted the Toda-Yamamoto approach to find the linear Granger causality relationship between short-term and long-term interest rates for the last seven business cycles in the U.S. and also for the last three business cycles in Canada. In the current chapter, we employed the Diks-Panchenko nonparametric method to examine the existence of nonlinear Granger causality relationship between these interest rates for the related periods.

In section 1 of the current study, we introduced our main goals and mentioned some of the advantages of the Diks-Panchenko (2006) test compared to other nonlinear Granger causality tests like the Baek-Brock (1992) and Hiemstra-Jones (1994) tests. Then, in section 2, the empirical methodology was discussed. Afterwards, in section 3, an explanation of the data sets and the results of unit root test for the residuals of estimated VAR models in the previous chapter were presented. In the same section, we also reported the DP nonlinear Granger causality test results. Comparing these results with those achieved in the previous chapter showed that there were some cases where the evidence of nonlinear causality could be detected between interest rates, whereas the linear causality relationships between them could not be found. Then, in section 4, the linear and nonlinear Granger causality directions were combined. It was seen that during the related periods in the U.S. and Canada, the most common Granger causality direction between FFR and ONR with other interest rates was a bidirectional one. Moreover, our findings were in contradiction with what had been found by some post-Keynesian structuralists such as Pollin.

To conclude, we must emphasise that policy makers must be aware of the weaknesses of the standard linear Granger causality test to find all the causality relationships between interest rates. Hence, to increase the accuracy of the tests, the possible existence of nonlinear Granger causality relationships between interest rates must be examined.

Investigating the main economic factors which lead to linear and nonlinear Granger causality relationships between short-term and long-term interest rates could be an interesting subject for future research. It seems that of some the main factors are inflation rates, exchange rates[1], international interest rates and international contracts.

Appendix

The DP nonlinear Granger causality test results, for $e = 1\sigma^2$, including the amount of T-statistic and rejection probability at each lag length of 1 to 6, for the U.S. are reported in Tables (2-11)' to (2-17)' and for Canada are presented in Tables (2-18)' to (2-20)'.[3] Each table relates to one business cycle.

[1]- For more information about the causality relationship between interest rates of two countries see Atesoglu and Smithin (2008).

[2]- Since, before applying the test, all variables are standardized, the standard deviation of the related series, σ, is equal to one.

[3]- In the Tables (2-11)' to (2-20)', *, *** and **** denote significance at the 1, 5 and 10 percent level, respectively.

Table (2-11)' - Nonlinear Granger Causality Test Results, Business Cycle 1 in the U.S. ($e = 1$)

H0: FFR does not cause PR		H0: PR does not cause FFR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
-0.5730	0.7167	0.0960	0.4619	1
-0.7750	0.7809	0.4510	0.3260	2
0.1220	0.4515	0.9030	0.1833	3
0.4670	0.3203	1.0620	0.1442	4
-0.1320	0.5523	0.8940	0.1857	5
-0.9020	0.8166	0.8270	0.2042	6
H0: FFR does not cause 6MTBR		H0: 6MTBR does not cause FFR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
-0.1700	0.5675	0.4720	0.3186	1
0.2850	0.3880	0.3550	0.3611	2
0.1780	0.4295	0.6980	0.2424	3
-0.4220	0.6636	0.0380	0.4847	4
-0.3950	0.6534	-0.2700	0.6065	5
-0.0660	0.5264	-0.7020	0.7587	6
H0: FFR does not cause 10YGBR		H0: 10YGBR does not cause FFR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
-0.2460	0.5972	0.1630	0.4351	1
1.0180	0.1544	0.4840	0.3141	2
0.9600	0.1684	-0.0150	0.5059	3
1.4320	0.0761***	0.0740	0.4706	4
0.5160	0.3028	1.0570	0.1452	5
1.0510	0.1465	0.4000	0.3445	6
H0: FFR does not cause 30YMR		H0: 30YMR does not cause FFR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
0.9200	0.1787	-0.7740	0.7805	1
0.4060	0.3423	-1.0120	0.8443	2
0.3400	0.3671	-0.5310	0.7021	3
-0.7580	0.7758	-0.8530	0.8032	4
-0.9390	0.8262	0.0210	0.4917	5
-0.8160	0.7929	0.6100	0.2711	6
H0: FFR does not cause BAACR		H0: BAACR does not cause FFR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
0.9740	0.1651	0.2530	0.4003	1
1.1320	0.1289	-0.0570	0.5228	2
0.9690	0.1664	-0.0940	0.5373	3
0.9480	0.1716	0.4240	0.3358	4
0.5110	0.3048	-0.3940	0.6531	5
0.4850	0.3139	-0.5070	0.6938	6

Table (2-12)' - Nonlinear Granger Causality Test Results, Business Cycle 2 in the U.S. ($e = 1$)

H0: FFR does not cause PR		H0: PR does not cause FFR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
0.7580	0.2242	1.9450	0.0259**	1
1.8120	0.0350**	1.8510	0.0321**	2
2.0240	0.0215**	1.2800	0.1002	3
1.7380	0.0411**	1.3200	0.0934***	4
1.8400	0.0329**	1.4430	0.0745***	5
1.6720	0.0473**	1.7010	0.0445**	6
H0: FFR does not cause 6MTBR		H0: 6MTBR does not cause FFR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
2.6310	0.0043*	3.6410	0.0001*	1
3.0260	0.0012*	4.2380	0.0000*	2
2.4330	0.0075*	3.6860	0.0001*	3
1.6980	0.0447**	3.3090	0.0005*	4
1.0520	0.1465	2.4450	0.0072*	5
0.8660	0.1932	2.0440	0.0205**	6
H0: FFR does not cause 10YGBR		H0: 10YGBR does not cause FFR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
0.6580	0.2553	2.0420	0.0206**	1
1.0500	0.1469	2.4470	0.0072*	2
0.8450	0.1990	-0.2380	0.5939	3
0.5400	0.2945	2.2640	0.0118**	4
1.3790	0.0839***	2.0490	0.0202**	5
0.7240	0.2345	1.6170	0.0530***	6
H0: FFR does not cause 30YMR		H0: 30YMR does not cause FFR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
1.8640	0.0312**	-0.5190	0.6982	1
2.7870	0.0027*	0.2470	0.4023	2
2.9980	0.0014*	-0.0130	0.5052	3
2.7230	0.0032*	0.5120	0.3045	4
0.5570	0.2889	0.6010	0.2740	5
1.1440	0.1263	0.6930	0.2441	6
H0: FFR does not cause BAACR		H0: BAACR does not cause FFR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
-0.4520	0.6744	2.3780	0.0087*	1
-0.2160	0.5856	2.6210	0.0044*	2
0.8370	0.2014	2.0620	0.0196**	3
0.5520	0.2904	1.9250	0.0271**	4
0.8320	0.2027	1.6900	0.0455**	5
1.2140	0.1123	1.2940	0.0979***	6

Table (2-13)' - Nonlinear Granger Causality Test Results, Business Cycle 3 in the U.S. $(e = 1)$

H0: FFR does not cause PR		H0: PR does not cause FFR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
0.9170	0.1797	1.1250	0.1303	1
1.2590	0.1041	1.7890	0.0368**	2
-0.0960	0.5382	0.7700	0.2207	3
-0.4050	0.6572	1.4110	0.0792***	4
-0.2820	0.6110	1.0760	0.1409	5
0.4660	0.3207	0.9410	0.1733	6
H0: FFR does not cause 6MTBR		H0: 6MTBR does not cause FFR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
1.1040	0.1349	-0.7190	0.7639	1
0.2780	0.3904	0.2300	0.4092	2
0.6810	0.2481	0.4390	0.3304	3
1.2060	0.1139	0.4520	0.3257	4
0.3440	0.3654	0.9640	0.1675	5
0.2200	0.4128	-0.8120	0.7916	6
H0: FFR does not cause 10YGBR		H0: 10YGBR does not cause FFR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
0.0980	0.4609	-0.6170	0.7315	1
-1.0980	0.8639	0.2630	0.3962	2
-0.2330	0.5921	-0.1080	0.5431	3
-0.4410	0.6703	-0.7420	0.7709	4
-0.1750	0.5693	-0.3120	0.6226	5
-	-	-	-	6
H0: FFR does not cause 30YMR		H0: 30YMR does not cause FFR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
1.8100	0.0352**	0.6090	0.2713	1
1.9590	0.0251**	0.2550	0.3995	2
1.0350	0.1504	-0.4410	0.6705	3
1.2720	0.1018	-0.6570	0.7445	4
0.0990	0.4604	-1.0860	0.8613	5
-0.4560	0.6756	-0.7470	0.7725	6
H0: FFR does not cause BAACR		H0: BAACR does not cause FFR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
0.1850	0.4268	0.6440	0.2598	1
0.8300	0.2034	0.5950	0.2760	2
0.6580	0.2551	0.7110	0.2386	3
-0.5590	0.7121	1.0370	0.1498	4
0.2920	0.3852	-0.1680	0.5666	5
0.0000	0.5000	0.5440	0.2932	6

Table (2-14)' - Nonlinear Granger Causality Test Results, Business Cycle 4 in the U.S. ($e = 1$)

H0: FFR does not cause PR		H0: PR does not cause FFR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
4.9780	0.0000*	2.0990	0.0179**	1
3.7210	0.0001*	2.5830	0.0049*	2
2.6050	0.0046*	1.3670	0.0858***	3
2.0340	0.0210**	2.4560	0.0070*	4
1.4510	0.0735***	1.8200	0.0344**	5
1.6790	0.0466**	1.2990	0.0970***	6
H0: FFR does not cause 6MTBR		H0: 6MTBR does not cause FFR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
2.8130	0.0025*	1.9700	0.0244**	1
2.9580	0.0016*	2.8180	0.0024*	2
1.9490	0.0256**	2.3190	0.0102**	3
1.2020	0.1147	2.8410	0.0023*	4
1.3230	0.0930***	2.0160	0.0219**	5
1.3310	0.0916***	1.6210	0.0525***	6
H0: FFR does not cause 10YGBR		H0: 10YGBR does not cause FFR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
1.0180	0.1543	2.0120	0.0221**	1
3.1180	0.0009*	2.8700	0.0021*	2
2.6610	0.0039*	2.0630	0.0195**	3
2.6250	0.0043*	1.4660	0.0714***	4
2.3170	0.0103**	0.8930	0.1859	5
1.6170	0.0530***	0.9660	0.1671	6
H0: FFR does not cause 30YMR		H0: 30YMR does not cause FFR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
0.9320	0.1755	0.1910	0.4244	1
-0.2060	0.5814	-0.1390	0.5553	2
-0.5220	0.6991	-1.1940	0.8838	3
-0.9320	0.8244	-0.5160	0.6971	4
-1.1360	0.8721	-0.5240	0.7000	5
-1.7510	0.9600	-0.4310	0.6666	6
H0: FFR does not cause BAACR		H0: BAACR does not cause FFR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
2.4870	0.0065*	2.5250	0.0058*	1
2.6770	0.0037*	2.9450	0.0016*	2
2.3270	0.0100*	2.2540	0.0121**	3
2.0980	0.0180**	1.7610	0.0391**	4
2.2100	0.0135**	1.5180	0.0645***	5
1.7160	0.0431**	1.4750	0.0701***	6

Table (2-15)' - Nonlinear Granger Causality Test Results, Business Cycle 5 in the U.S. ($e = 1$)

H0: FFR does not cause PR		H0: PR does not cause FFR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
3.1040	0.0010*	2.1500	0.0158**	1
2.7720	0.0028*	1.8570	0.0317**	2
1.8450	0.0325**	1.9160	0.0277**	3
1.2340	0.1086	1.1490	0.1253	4
1.6040	0.0544***	0.8560	0.1959	5
0.2740	0.3921	0.6050	0.2725	6
H0: FFR does not cause 6MTBR		H0: 6MTBR does not cause FFR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
2.3500	0.0094*	3.3110	0.0005*	1
2.3150	0.0103**	3.5060	0.0002*	2
1.8150	0.0348**	2.6210	0.0044*	3
0.8710	0.1917	2.2350	0.0127**	4
1.4250	0.0771***	1.2540	0.1050	5
0.9820	0.1630	0.6000	0.2743	6
H0: FFR does not cause 10YGBR		H0: 10YGBR does not cause FFR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
0.5470	0.2923	0.5500	0.2911	1
0.4110	0.3406	1.7090	0.0437**	2
0.6050	0.2726	0.7460	0.2277	3
0.8650	0.1936	0.5020	0.3079	4
0.6290	0.2648	0.3890	0.3485	5
0.8420	0.1998	1.1000	0.1356	6
H0: FFR does not cause 30YMR		H0: 30YMR does not cause FFR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
0.2050	0.4189	-0.0180	0.5072	1
0.4550	0.3246	1.6770	0.0468**	2
-0.4340	0.6679	1.2800	0.1002	3
0.6000	0.2742	1.9000	0.0287**	4
0.4800	0.3157	0.6090	0.2713	5
0.1270	0.4494	0.6930	0.2442	6
H0: FFR does not cause BAACR		H0: BAACR does not cause FFR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
0.4030	0.3434	-0.0620	0.5247	1
0.6100	0.2711	1.0250	0.1527	2
0.0290	0.4884	1.2570	0.1044	3
-0.2850	0.6123	0.9860	0.1620	4
0.3530	0.3622	0.9960	0.1597	5
1.0850	0.1389	0.2570	0.3984	6

Table (2-16)' - Nonlinear Granger Causality Test Results, Business Cycle 6 in the U.S. ($e = 1$)

H0: FFR does not cause PR		H0: PR does not cause FFR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
3.3220	0.0005*	3.0670	0.0011*	1
2.2620	0.0118**	2.1260	0.0168**	2
2.0020	0.0226**	1.9690	0.0245**	3
1.4950	0.0674***	1.9750	0.0241**	4
1.2970	0.0973***	1.5600	0.0593***	5
1.1630	0.1224	1.4840	0.0689***	6
H0: FFR does not cause 6MTBR		H0: 6MTBR does not cause FFR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
2.2010	0.0139**	2.8080	0.0025*	1
1.8520	0.0320**	2.6590	0.0039*	2
0.7860	0.2158	2.6470	0.0041*	3
0.0960	0.4619	2.4400	0.0073*	4
0.0940	0.4624	1.9370	0.0264**	5
0.0040	0.4983	1.8040	0.0356**	6
H0: FFR does not cause 10YGBR		H0: 10YGBR does not cause FFR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
-1.1650	0.8780	0.2810	0.3893	1
-0.4540	0.6751	0.4070	0.3420	2
-0.4060	0.6577	0.4370	0.3311	3
0.0040	0.4984	-0.3160	0.6240	4
-0.7250	0.7657	0.5260	0.2994	5
-0.7150	0.7627	0.2670	0.3948	6
H0: FFR does not cause 30YMR		H0: 30YMR does not cause FFR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
-0.5910	0.7227	-0.7870	0.7844	1
-1.5780	0.9427	-0.1930	0.5765	2
-0.5630	0.7134	-0.0780	0.5312	3
-0.2250	0.5892	0.7060	0.2402	4
-0.1130	0.5450	0.6250	0.2659	5
-0.0390	0.5156	0.3080	0.3791	6
H0: FFR does not cause BAACR		H0: BAACR does not cause FFR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
-1.7720	0.9618	-0.4160	0.6613	1
-1.2130	0.8875	-0.1220	0.5485	2
-0.7200	0.7643	0.7280	0.2335	3
0.0700	0.4693	-0.0460	0.5184	4
-0.3950	0.6536	0.6600	0.2545	5
-0.3890	0.6514	0.2590	0.3976	6

Table (2-17)' - Nonlinear Granger Causality Test Results, Business Cycle 7 in the U.S. ($e = 1$)

H0: FFR does not cause PR		H0: PR does not cause FFR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
1.1440	0.1264	2.2610	0.0119**	1
2.3740	0.0088*	2.4130	0.0079*	2
1.2620	0.1035**	2.1350	0.0164**	3
1.7230	0.0425**	2.1760	0.0148**	4
1.4530	0.0731***	2.0720	0.0191**	5
1.0330	0.1508	1.8280	0.0338**	6
H0: FFR does not cause 6MTBR		H0: 6MTBR does not cause FFR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
3.7530	0.0001*	3.3450	0.0004*	1
2.7630	0.0029*	2.7420	0.0031*	2
2.5190	0.0059*	1.9300	0.0268**	3
1.7790	0.0376**	1.4880	0.0684***	4
1.4860	0.0687***	1.6200	0.0526***	5
1.2690	0.1022	1.0360	0.1500	6
H0: FFR does not cause 10YGBR		H0: 10YGBR does not cause FFR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
1.9080	0.0282**	0.9030	0.1833	1
2.4940	0.0063*	2.5100	0.0060*	2
1.5260	0.0635***	2.3350	0.0098*	3
0.7940	0.2136	1.1460	0.1259	4
0.6600	0.2547	1.7370	0.0412**	5
-0.2450	0.5968	1.9140	0.0278**	6
H0: FFR does not cause 30YMR		H0: 30YMR does not cause FFR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
1.1350	0.1281	2.0010	0.0227**	1
1.5090	0.0656***	2.5820	0.0049*	2
1.5270	0.0634***	1.8120	0.0350**	3
1.8640	0.0312**	1.4140	0.0787***	4
1.8940	0.0291**	1.7080	0.0439**	5
1.1750	0.1201	2.0000	0.0228**	6
H0: FFR does not cause BAACR		H0: BAACR does not cause FFR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
-0.2930	0.6154	2.9830	0.0014*	1
1.6480	0.0496**	2.8670	0.0021*	2
1.0940	0.1370	3.5640	0.0002*	3
0.5020	0.3078	2.8290	0.0023*	4
0.6900	0.2452	3.1320	0.0009*	5
0.5320	0.2973	2.6190	0.0044*	6

Table (2-18)' - Nonlinear Granger Causality Test Results, Business Cycle 1 in Canada ($e = 1$)

H0: ONR does not cause PR		H0: PR does not cause ONR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
2.822	0.00238*	4.415	0.00001*	1
3.426	0.00031*	4.351	0.00001*	2
2.803	0.00253*	3.590	0.00017*	3
1.825	0.03403**	3.030	0.00122*	4
1.781	0.03744**	2.527	0.00575*	5
1.888	0.02952**	2.040	0.02066**	6
H0: ONR does not cause 6MTBR		H0: 6MTBR does not cause ONR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
2.495	0.00630*	4.341	0.00001*	1
3.105	0.00095*	4.927	0.00000*	2
2.926	0.00172*	4.106	0.00002*	3
1.710	0.04366**	3.576	0.00017*	4
1.953	0.02541**	2.731	0.00316*	5
2.099	0.01792**	3.285	0.00051*	6
H0: ONR does not cause 10YGBR		H0: 10YGBR does not cause ONR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
-0.244	0.59630	2.552	0.00535*	1
-0.371	0.64466	2.854	0.00216*	2
-1.106	0.86567	1.970	0.02440**	3
-1.035	0.84972	1.958	0.02510**	4
-1.245	0.89343	1.553	0.06021***	5
0.292	0.38524	0.920	0.17881	6
H0: ONR does not cause LTGBR		H0: LTGBRR does not cause ONR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
1.859	0.03153**	3.739	0.00009*	1
2.752	0.00296*	3.697	0.00011*	2
2.056	0.01988**	2.902	0.00185*	3
1.623	0.05228***	2.513	0.00598*	4
1.250	0.10563	2.279	0.01134**	5
0.731	0.23247	2.183	0.01453**	6
H0: ONR does not cause 5YMR		H0: 5YMR does not cause ONR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
-0.029	0.51150	1.998	0.02286**	1
0.189	0.42497	2.017	0.02187**	2
0.203	0.41975	2.178	0.01471**	3
-0.659	0.74489	1.421	0.07767***	4
-0.662	0.74591	1.398	0.08102***	5
-0.903	0.81683	1.175	0.12008	6

Table (2-19)' - Nonlinear Granger Causality Test Results, Business Cycle 2 in Canada ($e = 1$)

H0: ONR does not cause PR		H0: PR does not cause ONR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
4.508	0.00000*	5.209	0.00000*	1
5.782	0.00000*	5.349	0.00000*	2
6.112	0.00000*	4.570	0.00000*	3
5.600	0.00000*	3.931	0.00004*	4
4.953	0.00000*	4.341	0.00001*	5
4.747	0.00000*	4.281	0.00001*	6
H0: ONR does not cause 6MTBR		H0: 6MTBR does not cause ONR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
5.550	0.00000*	5.813	0.00000*	1
5.424	0.00000*	6.797	0.00000*	2
4.924	0.00000*	6.215	0.00000*	3
4.303	0.00001*	5.352	0.00000*	4
3.780	0.00008*	4.857	0.00000*	5
3.302	0.00048*	4.401	0.00001*	6
H0: ONR does not cause 10YGBR		H0: 10YGBR does not cause ONR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
3.551	0.00019*	3.958	0.00004*	1
3.000	0.00135*	5.285	0.00000*	2
3.585	0.00017*	5.141	0.00000*	3
3.430	0.00030*	4.709	0.00000*	4
2.839	0.00226*	4.162	0.00002*	5
2.386	0.00851*	3.750	0.00009*	6
H0: ONR does not cause LTGBR		H0: LTGBRR does not cause ONR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
3.448	0.00028*	3.119	0.00091*	1
3.765	0.00008*	5.016	0.00000*	2
3.919	0.00004*	4.935	0.00000*	3
3.715	0.00010*	4.911	0.00000*	4
3.020	0.00126*	4.334	0.00001*	5
2.532	0.00568*	3.752	0.00009*	6
H0: ONR does not cause 5YMR		H0: 5YMR does not cause ONR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
1.023	0.15305	0.789	0.21492	1
1.411	0.07913***	2.083	0.01862*	2
0.145	0.44239	2.335	0.00978*	3
1.327	0.09221***	2.718	0.00328*	4
1.245	0.10658	2.568	0.00511*	5
0.319	0.37505	2.113	0.01729**	6

Table (2-20)' - Nonlinear Granger Causality Test Results, Business Cycle 3 in Canada ($e = 1$)

H0: ONR does not cause PR		H0: PR does not cause ONR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
3.292	0.00050*	3.839	0.00006*	1
2.997	0.00136*	3.337	0.00042*	2
2.602	0.00463*	2.861	0.00211*	3
1.586	0.05634***	2.339	0.00968*	4
1.157	0.12356	1.722	0.04255**	5
1.168	0.12133	2.116	0.01716**	6
H0: ONR does not cause 6MTBR		H0: 6MTBR does not cause ONR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
2.546	0.00546*	2.711	0.00336*	1
1.475	0.07016***	2.587	0.00484*	2
1.647	0.04976**	2.755	0.00293*	3
1.407	0.07971***	2.852	0.00217*	4
1.171	0.12071	2.189	0.01431**	5
0.988	0.16158	2.073	0.01909**	6
H0: ONR does not cause 10YGBR		H0: 10YGBR does not cause ONR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
0.745	0.22802	2.140	0.01616**	1
0.633	0.26347	1.143	0.12647	2
1.320	0.09339***	1.198	0.11551	3
-0.267	0.60521	1.469	0.07096***	4
0.378	0.35275	1.817	0.03460**	5
0.553	0.29021	1.491	0.06795***	6
H0: ONR does not cause LTGBR		H0: LTGBRR does not cause ONR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
-0.207	0.58211	1.537	0.06216***	1
0.422	0.33637	1.267	0.10258	2
1.398	0.08106***	0.442	0.32926	3
0.485	0.31385	0.662	0.25392	4
0.578	0.28172	1.171	0.12081	5
1.066	0.14311	0.846	0.19866	6
H0: ONR does not cause 5YMR		H0: 5YMR does not cause ONR		Lx=Ly
T- Statistics	Probability	T- Statistics	Probability	
0.805	0.21029	1.900	0.02869**	1
1.387	0.08273***	1.600	0.05476***	2
0.831	0.20286	0.742	0.22918	3
1.128	0.12963	1.643	0.05022***	4
0.848	0.19820	1.657	0.04873**	5
0.525	0.29975	2.011	0.02216**	6

Chapter 3

Linear and Nonlinear Granger-causality between Short-term and Long-term Interest Rates

"Rolling Window Strategy"

3.1 Introduction

As was mentioned in the literature review section of the first chapter, some post-Keynesian economists, like Pollin (2008, p. 24), believe that there is a significant two-way causation between the federal funds rate and the market interest rates, with the exception of the prime rate. But, these causations become insignificant for the last business cycle up to 2008. Pollin believes that financial market deregulation in the capital economy leads to systematic instability in the financial markets and this instability decreases the degree of interest rate exogeneity.

In the first and second chapters of this thesis, we employed the Granger causality tests to detect the linear and nonlinear causal relationships between short-term and long-term interest rates during different business cycles. Then, we compared our findings with Pollin's results.

Since the durations of business cycles are different, they include different numbers of observations and this fact may affect the Granger causality test results. Therefore, in the current chapter, to explore whether the significant causality directions between short-term and long-term interest rates would change with the passing of time, we apply Granger causality tests in the context of a rolling window strategy. In this method, the tests are applied for a fixed length estimation sub-sample that moves through time.

Moreover, the results in the previous chapters showed that the Granger causality relationship between short-term and long-term interest rates cannot just be found by simply employing the traditional linear Granger causality test. In other words, in addition to the simple linear causal relationships between variables, there may exist nonlinear ones, so detecting them requires applying nonlinear Granger causality tests. Therefore, in this chapter, like in the previous ones, both the linear and nonlinear Granger causality tests are employed for all estimation sub-samples.

This chapter, by introducing a rolling window strategy to find the linear and nonlinear Granger causality directions between short-term and long-term interest rates, contributes to the literature on the interest rate relationship.

The remainder of this chapter is set out as follows: Section 2 offers the empirical methodology. The empirical analysis is presented in section 3. This section contains a description of the data sets, the results of unit root tests and also the results of the linear and nonlinear Granger causality tests. In section 4, we combine the linear and nonlinear Granger causality test results. Finally, a summary and the most important conclusions are provided in section 5.

3.2 Empirical Methodology

Here we briefly explain the empirical methodology that is used in this chapter.

Rolling Window Strategy

In order to capture the dynamic causal relationships between short-term and long-term interest rates, we apply a rolling window strategy. To make this methodology clear, consider x_t and y_t as two univariate time series for $t = 1, 2, \dots, T$. By setting the window (sub-sample) length equal to a fixed number like m, $m < T$, the i^{th} window of each series would be defined over $t = i, i + 1, \dots, i + m - 1$. For example the first m-length sub-sample (window) is defined over $t = 1, 2, \dots, m$ and the second one is defined over $t = 2, 3, \dots, m + 1$, and so on. Therefore, for each series with T number of observations, we have $T - m + 1$ sub-samples. Now, we can apply the linear and nonlinear Granger causality tests for each sub-sample.

Granger Causality Definition[1] (Review)

Consider two strictly stationary time series X_t and Y_t. X_t Granger-causes Y_t if its current and previous values contain information, in addition to what is contained in the current and previous values of Y_t, that can significantly affect future values of Y_t. In other words, X_t Granger causes Y_t if for $s \geq 1$:

$$(Y_{t+1}, \dots, Y_{t+s})|(I_{X_t}, I_{Y_t}) \nsim (Y_{t+1}, \dots, Y_{t+s})|(I_{Y_t}) \qquad (1)$$

I_{X_t} and I_{Y_t} contain the information in the past and current observations of X_t and Y_t respectively, and ~ denotes equivalence in distribution.

Linear Granger Causality Test [2]

For the above two strictly stationary time series X_t and Y_t, the statistically significant power of past values of X_t in prediction of Y_t and vice versa can be tested by the following linear VAR model:

$$x_t = \alpha_{10} + \sum_{p=1}^{P_{11}} \beta_{1p}\, x_{t-p} + \sum_{p=1}^{P_{12}} \gamma_{1p}\, y_{t-p} + u_{1t} \qquad (2)$$

$$y_t = \alpha_{20} + \sum_{p=1}^{P_{21}} \beta_{2p}\, x_{t-p} + \sum_{p=1}^{P_{22}} \gamma_{2p}\, y_{t-p} + u_{2t} \qquad (3)$$

[1]- Diks and Panchenko (2006)

[2]- Granger (1969)

where P_{ij} for $i, j = 1, 2$ refers to the lag length of the related variable. If with the help of Wald test, the null hypothesis $H_0: \gamma_{1p} = 0$ for $p = 1, 2, \dots, P_{12}$, statistically, is rejected in favour of $H_A: not\ H_0$, then Y_t linearly Granger causes X_t. If H_0 cannot be rejected, then Y_t does not Granger causes X_t. In the same way, if the null hypothesis $H_0: \beta_{2p} = 0$ for $p = 1, 2, \dots, P_{21}$ is rejected in favour of $H_A: not\ H_0$, then X_t Granger causes Y_t linearly. Otherwise, it does not cause Y_t.

Nonlinear Granger Causality Test

For nonlinear Granger causality test, we apply Diks and Panchenko nonparametric approach[1] for the residuals that are obtained from the linear VAR models. In other words, we take the residuals from equations (2) and (3) as below:

$$u_{1t} = x_t - \alpha_{10} - \sum_{p=1}^{P_{11}} \beta_{1p}\, x_{t-p} - \sum_{p=1}^{P_{12}} \gamma_{1p}\, y_{t-p} \qquad (4)$$

$$u_{2t} = y_t - \alpha_{20} - \sum_{p=1}^{P_{21}} \beta_{2p}\, x_{t-p} - \sum_{p=1}^{P_{22}} \gamma_{2p}\, y_{t-p} \qquad (5)$$

Then, we apply Diks and Panchenko nonlinear test for u_{1t} and u_{2t}. A brief explanation of this test is presented in follow.

Again consider two stationary time series X_t and Y_t. Also, consider $X_t^{l_x} = (X_{t-l_x-1}, \dots, X_t)$ and $Y_t^{l_x} = (Y_{t-l_x-1}, \dots, Y_t)$ for l_x , $l_y \geq 1$.

If in equation (1), we set $s = 1$, then the null hypothesis in the non-causality Granger test can be written as follows:

---

[1]- Diks and Panchenko (2006)

$$H_0 : Y_{t+1} \left| \left(X_t^{l_x} ; Y_t^{l_y} \right) \sim Y_{t+1} \right| Y_t^{l_y} \tag{6}$$

and we have the following test statistics:

$$T_n(e) = \frac{n-1}{n(n-2)} \sum_i (\hat{f}_{X,Y,Z}(X_i \ Y_i, Z_i) \hat{f}_Y(Y_i) - \hat{f}_{X,Y}(X_i, Y_i) \hat{f}_{Y,Z}(Y_i, Z_i)) \tag{7}$$

$\hat{f}_K(K_i)$ is a the local density estimator of K_i, $\hat{f}_K(K_i) = (2e)^{-d_k}(n-1)^{-1} \sum_{i,j \neq i} I_{ij}^K$ where $I(\cdot)$ is an indicator function defined by $I_{ij}^K = I(\|K_i - K_j\| < e)$ in which e is the bandwidth such that $e = Cn^{-\beta} \quad C > 0$, $\frac{1}{4} < \beta < \frac{1}{3}$. According to Diks and Panchenko (2006), the above mentioned statistics satisfies

$$\sqrt{n} \, \frac{(T_n(e) - q)}{S_n} \xrightarrow{D} N(0,1) \tag{8}$$

Where q and S_n are the estimator of asymptotic expectation and standard error respectively.

3.3 Empirical Analysis

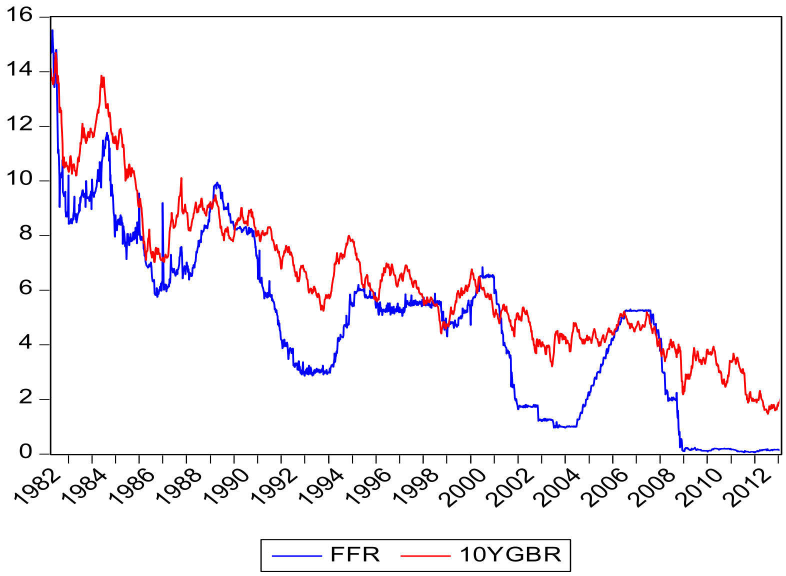
3.3.1 Data

To increase precision, in the current chapter, we focus only on two interest rates in the United States. The federal funds rate (FFR) is considered as the short-term interest rate and the 10-Year Government Bond Rate (10YGBR) is representative of long-term interest rates. We use weekly data and our sample contains 1611 observations from April 9, 1982 to February 15, 2013 which is taken from the Federal Reserve Bank of St. Louis database[1]. The behaviour of these two interest rates for the related period is illustrated in Figure (3-1).

[1]- http://research.stlouisfed.org

Figure (3-1) - Federal Funds Rate and 10-Year Government Bond Rate Behaviors

(April 1982 to February 2013)



In this study the total number of observations (T) equals 1611; and the sub-sample length (m) is set at 300 weeks.[1] Therefore, according to what was explained in the Empirical Methodology section, every test is done 1312 ($T - m + 1$) times.

3.3.2 Unit Root Test

Before applying the Granger causality tests, the Augmented Dickey-Fuller (ADF)[2] and the Philips-Peron (PP)[3] unit root tests, including trend and intercept, are used. The significance probability, related to the null hypothesis that a variable has a unit root, is shown in Figures (3-2) and (3-3).

[1]- We also set it at 250 and 400 weeks and then applied all the tests. However, the results were almost the same.

[2]- Dickey and Fuller (1979)

[3]- Philips and Peron (1988)

Figure (3-2) - Unit Root Test Results for the Federal Funds Rate

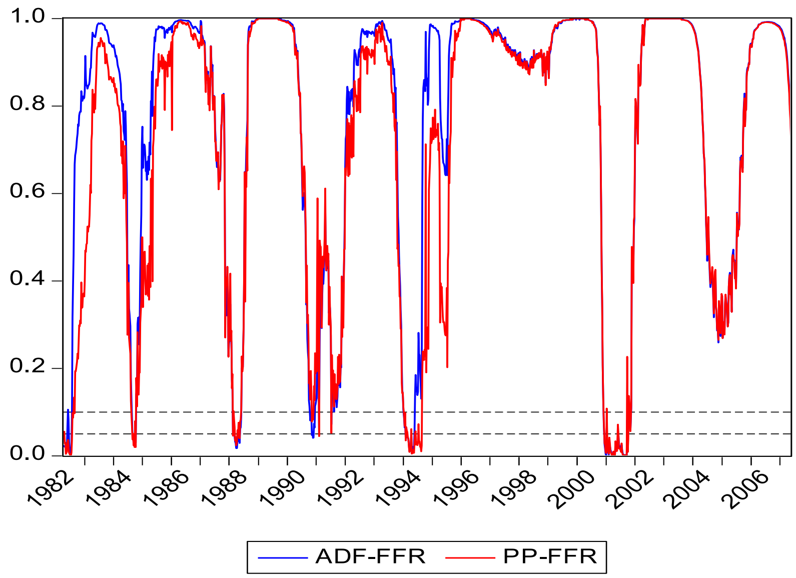
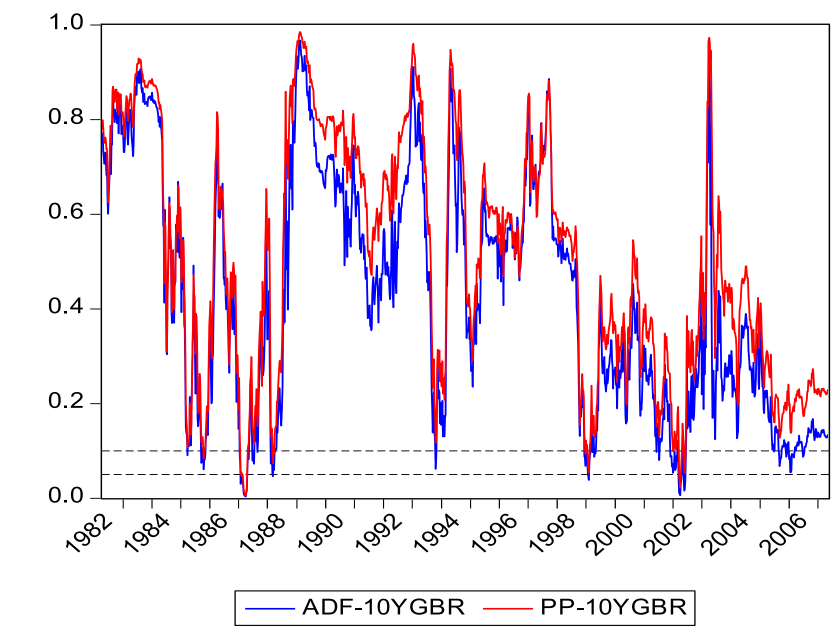
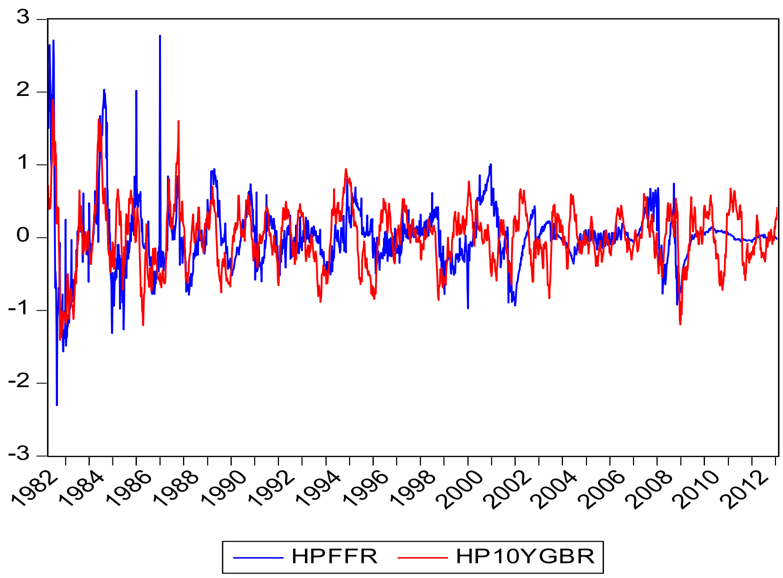


Figure (3-3) - Unit Root Test Results for 10-Year Government Bond Rate



In these figures, the horizontal axis implies the start time for every sub-sample and the horizontal dashed lines show 5% and 10% probabilities. We can see that in most of the windows, both variables are non-stationary. To make the series stationary, the Hodrick-Prescott[1] filter has been used. In addition to de-trending time series, this technique keeps all fluctuations. The filtered series behaviors are presented in Figure (3-4).

Figure (3-4) - Hodrick-Prescott Filtered Federal Funds Rate and 10-Year Government Bond Rate Behaviors (April 1982 to February 2013)



After de-trending our variables, the Augmented Dickey-Fuller (ADF) unit root test is applied again (this time without trend) and the results are presented in Figures (3-5) and (3-6). They show that, except in very few cases, HPFFR and HP10YGRBR are stationary respectively at the 95% and 90% significance levels. Now we can proceed and apply the linear and nonlinear Granger causality tests.

[1]- Hodrick and Prescott (1997)

Figure (3-5) - Augmented Dickey-Fuller Unit Root Test Results for Hodrick-Prescott Filtered Federal Funds Rate

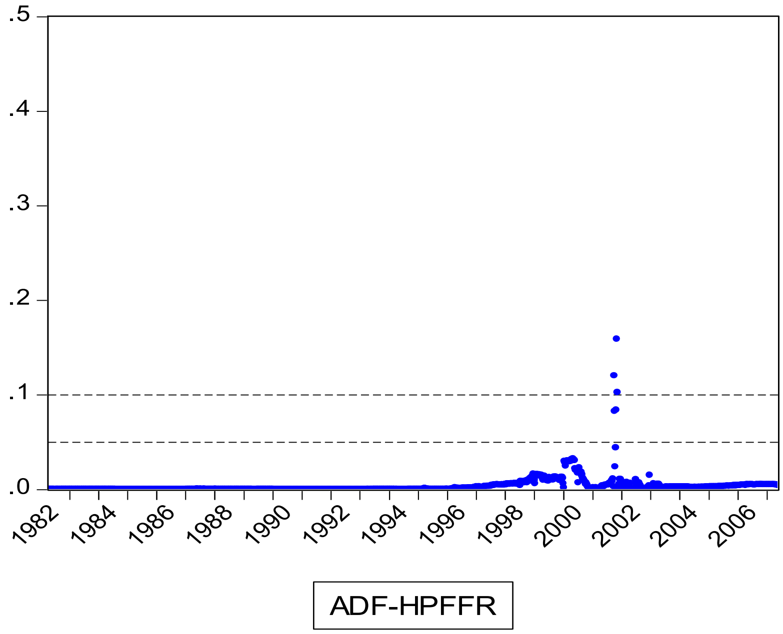
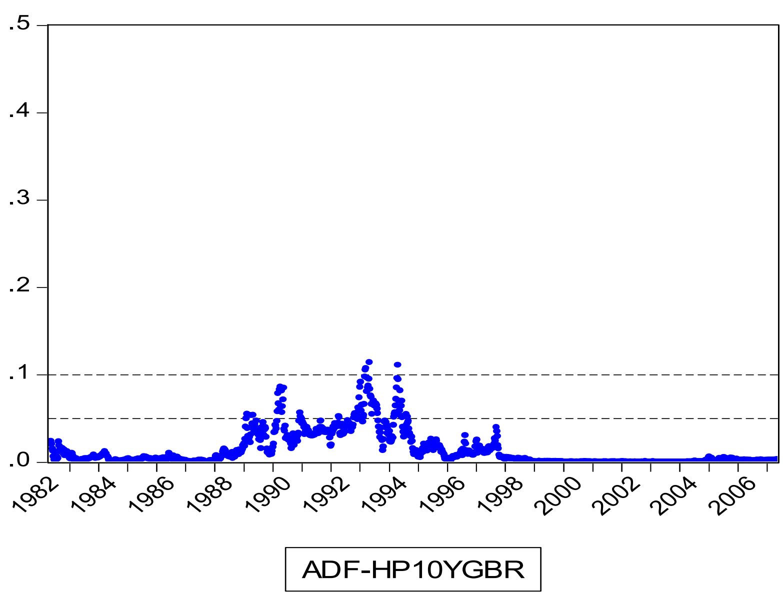


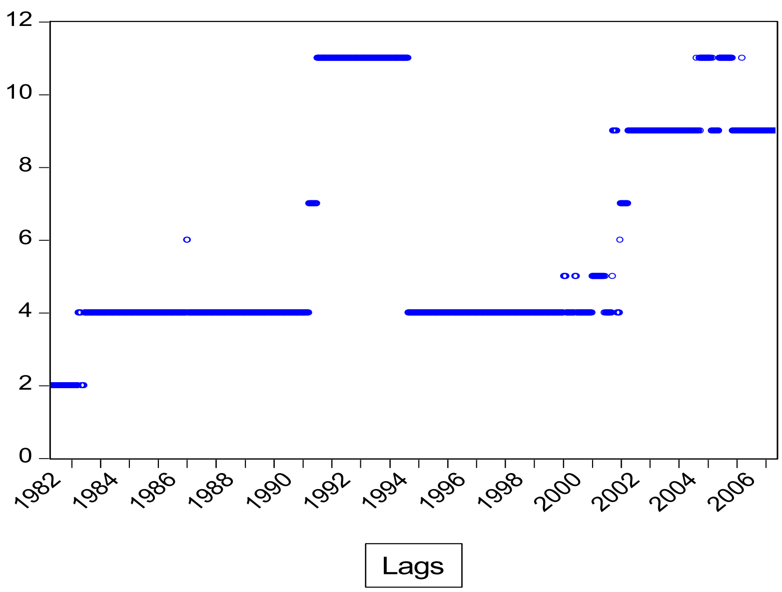
Figure (3-6) - Augmented Dickey-Fuller Unit Root Test Results for Hodrick-Prescott Filtered 10-Year Government Bond Rate



3.3.3 Linear Granger Causality Test

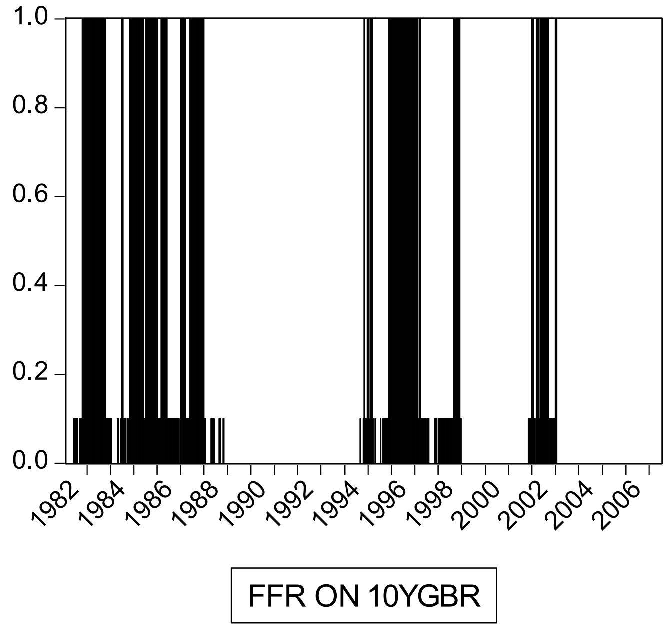
In this study, the maximum lag order for the VAR models is set at 12 and the best lag length, for each sub-sample, is chosen according to the Akaike Information Criteria. In Figure (3-7), each dot shows the best lag for the corresponding estimation window.

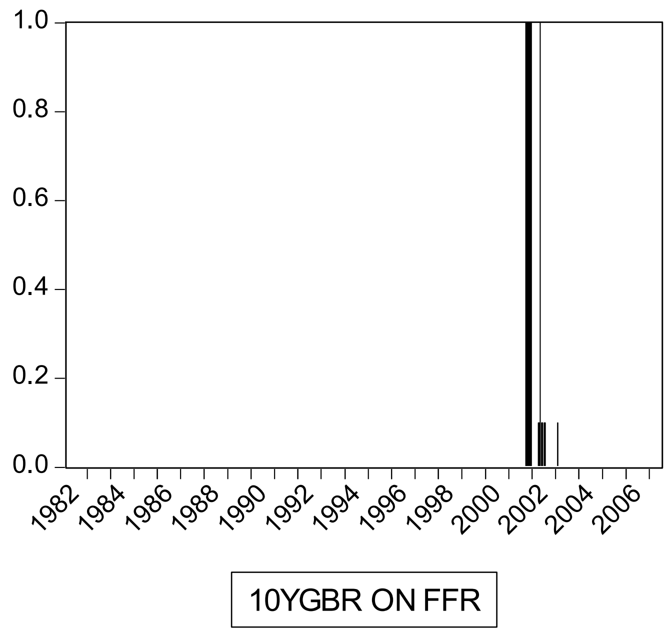
Figure (3-7) - The Best Lag length According to AIC



In order to visualize the obtained results, this paper follows the method that is applied by Zhang, Lai and Wang (2009). We give the number zero to the significance probabilities which are smaller than or equal to 0.05. The significance probabilities that are less than or equal to 0.1 and greater than 0.05 are given the value of 0.1. Finally, the probabilities greater than 0.1 get the value of 1. We call this new variable P_l . Therefore, when P_l is zero, it means that the null hypothesis is rejected at the 95% significance level and when it takes 0.1, it implies that the null hypothesis is rejected at the 90% significance level. Otherwise, meaning when P_l is equal to 1, the null hypothesis cannot be rejected. The results of linear Granger causality test are shown in Figure (3-8).

Figure (3-8) – Linear Granger Causality Test Results





The first panel of Figure (3-8) shows that for some of estimated sub-samples that start between 1982-1988, 1995-1999 and 2002-2003, FFR does not linearly Granger cause 10YGBR significantly. The second panel of Figure (3-8) shows that during a few sub-samples that start at the end of 2001, 10YGBR does not Granger cause FFR linearly. In the sub-samples that do not start in the above mentioned periods, there is a significant bidirectional linear causal relationship between FFR and 10YGBR.

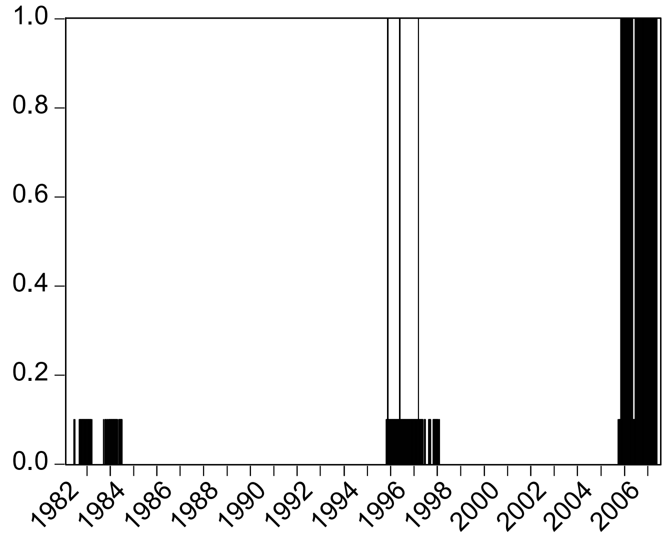
In general, the results show that the linear causality relationship between FFR and 10YGBR changes through time. However, it seems that the linear causality effect of FFR on 10YGBR is increasing with the passing of time. By contrast, it seems that in nearly all rolling periods, 10YGBR does Granger-cause FFR, meaning the long-term interest rate has a linear impact on future federal funds rate.

3.3.4 Nonlinear Granger Causality Test

In conducting the DP nonlinear Granger causality test for two series of residuals such as X and Y that are obtained from the linear VAR models, we set the lag length of variable X equal to the lag length of variable Y, that is $L_x = L_y$ [1]. In order to verify the robustness of the test, we apply it for the lag length of 1 to 12 and for two bandwidth $e = 1.5\,\sigma$ and $e = 1\,\sigma$. Between different lag lengths of 1 to 12, the smallest significance probability has been chosen. Since, before employing the test, all variables are standardized, the standard deviation of the related series, σ, is equal to one. Again the test results for the rolling window strategy are visualized according to the method that has been explained in the above section. At this time, we call the new defined variable P_{nl} . The visualized findings for $e = 1.5$ and $e = 1$ are presented in Figures (3-9) and (3-10) respectively.

[1]- Hiemstra and Kramer (1997)

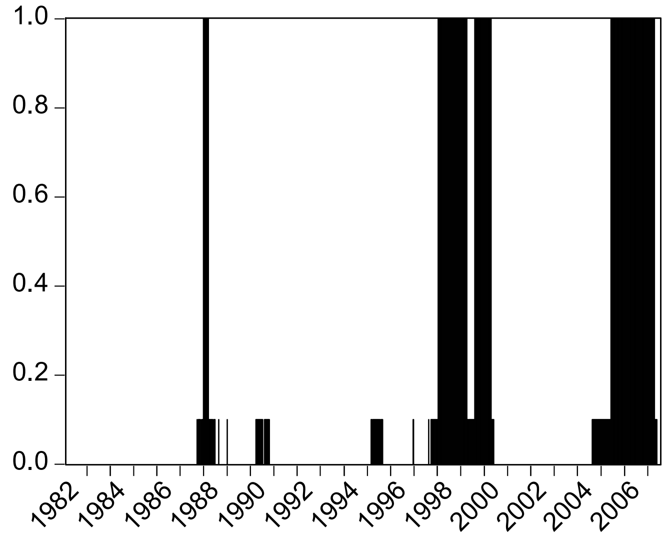
Figure (3-9) – Nonlinear Granger Causality Test Results, e=1



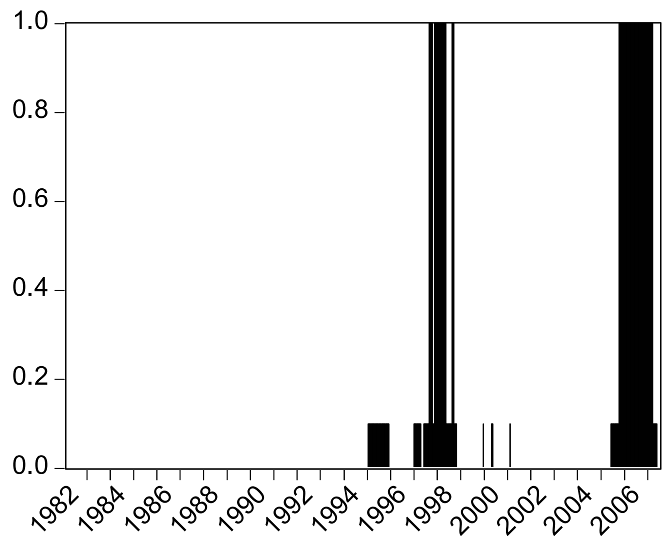
FFR ON 10YGBR

10YGBR ON FFR

Figure (3-10) – Nonlinear Granger Causality Test Results, e=1.5



FFR ON 10YGBR



10YGBR ON FFR

One can see that causality relationships between FFR and 10YGBR are time varying. However, in general, we can observe that for each bandwidth, the dynamic nonlinear causal relationships between FFR and 10YGBR are almost the same. Moreover, the figures demonstrate that with the passage of time, the nonlinear causality effects between these two interest rates diminish.

The first panel of Figure (3-10) illustrates that for the estimation sub-samples that start during November 2005 to May 2007, and also for a couple of sub-samples that start in 1995, 1996 and 1997, FFR does not Granger cause 10YGBR nonlinearly.

Moreover, the second panel of Figure (3-10) shows that for the estimated windows that start during the middle of 2005 to the middle of 2007, 10YGBR does not cause FFR significantly.

By changing the bandwidth from e=1 to e=1.5, the number of periods, in which FFR and 10YGBR do not cause each other, increases. As demonstrated in the first panel of Figure (3-11), for most of the estimation windows that start during three periods, there is no nonlinear causality effect from FFR to 10YGBR. These periods are as follows: from January 1988 to May 1988, from January 1998 to May 2000 and from June 2005 to April 2007. Also, the results show that for most of samples that start from August 1997 to September 1998 and also for those that start from October 2005 to March 2007, 10YGBR does not cause FFR.

Besides the above mentioned periods, there is a significant two-way nonlinear causation between FFR and 10YGBR.

3.3.5 Combined Linear and Nonlinear Granger Causality

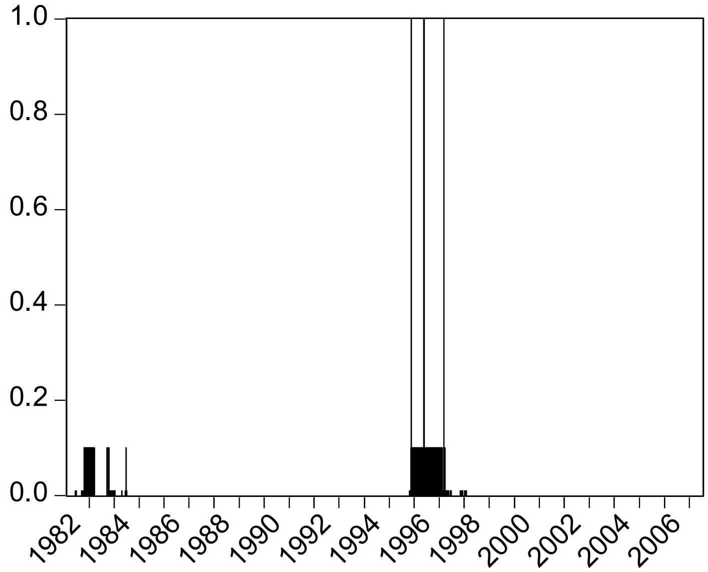
By comparing Figures (3-8) to (3-10), we can see that for some sub-samples, we were able to detect evidence of nonlinear causal relationships between FFR and 10YGBR, whereas we could not find linear causality between them and vice versa.

Now, according to what we obtained in the linear and nonlinear Granger causality parts, the total (linear and nonlinear) Granger causality directions between FFR and 10YGBR can be derived. For example, as can be observed in the first panel of Figure (3-8), for some of the estimation sub-samples that start during 2002 to 2003, FFR does not linearly Granger cause 10YGBR; However, for theses sub-samples, as it is demonstrated in the first panel of Figures (3-9) and (3-10), we found a significant nonlinear causal relationship from FFR to 10YGBR. Therefore, by combining these two results, we can say that during these estimation windows, FFR Granger causes 10YGBR significantly, either linearly or nonlinearly.

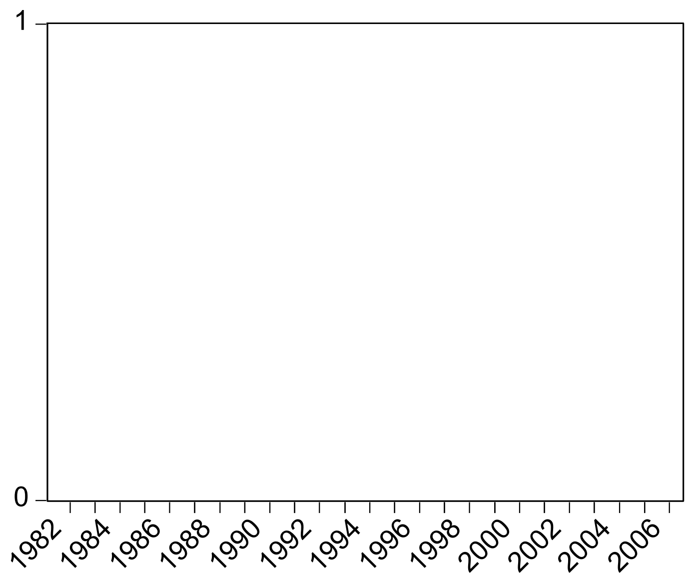
As another example, consider the second panel of Figure (3-8). According to the results, for the estimation windows that begin during 2006 to 2007, 10YGBR linearly Granger causes FFR whereas, the second panel of Figures (3-9) and (3-10) shows that for the above estimation sub-samples, 10YGBR does not nonlinearly cause FFR. Hence, it can be said that during theses estimation sub-samples, 10YGBR Granger causes FFR significantly, either linearly or nonlinearly.

The total Granger causality based on linear and nonlinear, at two different bandwidths of e=1 and e=1.5, are visualized with the help of Figures (3-11) and (3-12).

Figure (3-11) - Total (Linear and Nonlinear (e=1)) Granger causality

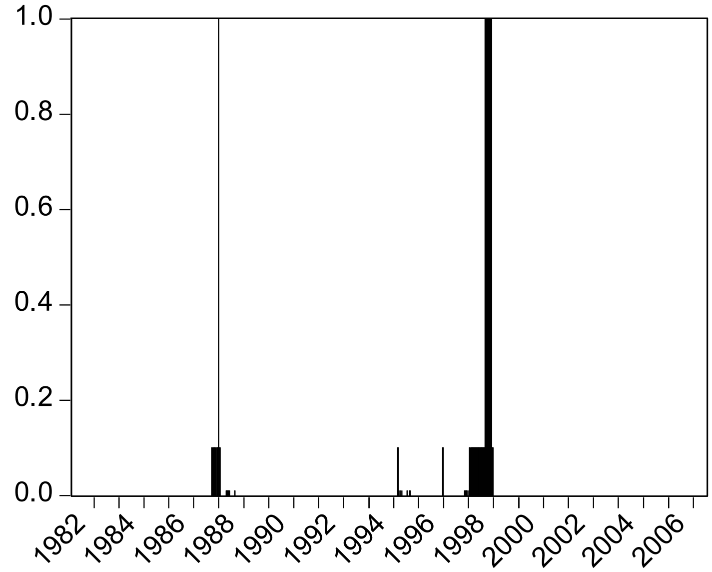


FFR ON 10YGBR

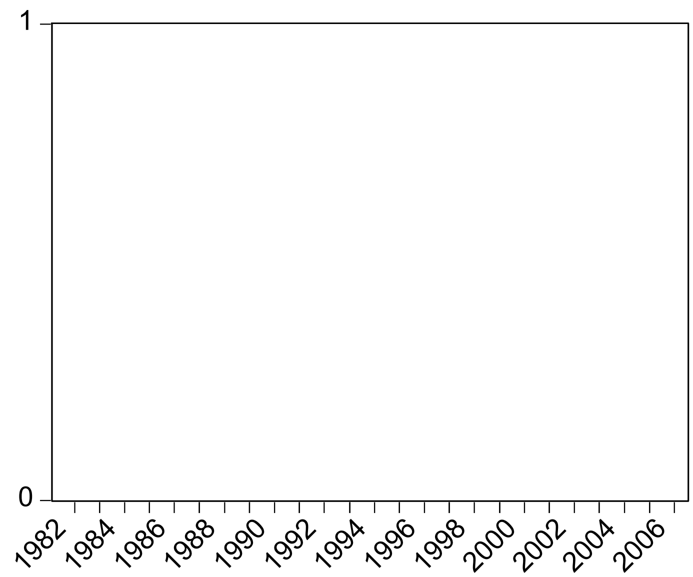


10YGBR ON FFR

Figure (3-12) - Total (Linear and Nonlinear (e=1.5)) Granger causality



FFR ON 10YGBR



10YGBR ON FFR

For visualizing, we create a new variable and call it P_t. This variable is obtained by multiplying P_l and P_{nl} . Therefore it takes four different values as follows:

$$P_t = \begin{cases} 0 & if\ P_l = 0\ or\ P_{nl} = 0 \\ 1 & if\ P_l = 1\ and\ P_{nl} = 1 \\ 0.1 & if\ P_l\ (P_{nl}) = 1\ and\ P_{nl}\ (P_l) = 0.1 \\ 0.01 & if\ P_l = 0.1\ and\ P_{nl} = 0.1 \end{cases}$$

In other words, it takes zero if for the related sub-sample, FFR (10YGBR) Granger causes 10YGBR (FFR) linearly or nonlinearly at 5% significance probability. Also, it gets 1 if FFR (10YGBR) does not Granger cause 10YGBR (FFR) neither linearly nor nonlinearly. P_t gets 0.1 if FFR (10YGBR) does not cause 10YGBR (FFR) linearly (nonlinearly) level while it causes 10YGBR (FFR) nonlinearly (linearly) at 90% significant level. And finally, it takes 0.01 if FFR (10YGBR) Granger causes 10YGBR (FFR) linearly and nonlinearly at 90% significance level. In Figures (3-11) and (3-12), the vertical axis shows the values of P2 and the horizontal axis shows the start time for each sub-sample.

The first panel of these two figures demonstrates that in most of the sub-samples, FFR linearly or nonlinearly Granger causes 10YGBR with the exception of a few sub-samples. The second panel of these figures shows that 10YGBR Granger causes FFR in all of the estimation sub-samples. This causality is significant at the 0.05 significance probability in all of the sub-samples. Therefore, according to our findings, it can be concluded that there is a bidirectional Granger causality relationship (linear or nonlinear or both) between FFR and 10YGBR during different time horizons.

Since FFR is a monetary instrument in the hands of the Federal Reserve, it acts as an exogenous variable and Granger causes 10YGBR. Also, 10YGBR is formed based on the current and expected values of short-term interest rates. Therefore, it is obvious that this rate, as long as expectations are not entirely mistaken, can help to predict FFR, or, in the other words, it Granger causes FFR significantly.

The results of our research contradict some of Pollin's findings. As was explained in the "Literature Review" section of the first chapter, Pollin (2008) believes that with the passing of time, the causality effect of the federal funds rate on the long-term interest rate is decreasing. He mentioned that *"...whatever degree of causation that had existed in previous periods has broken down in most recent cycle, to the point of insignificance."* (Pollin, 2008, p. 11) He believes that financial market deregulation in the capitalist economy leads to systematic instability in the financial markets and that this instability increases the endogeneity of interest rates. But, our findings reject Pollin's results.

3.3.6 Robustness Check

As was mentioned above, in order to verify the robustness of the test, we applied it for the lag length of 1 to 12 and for two bandwidth $e = 1.5\,\sigma$ and $e = 1\,\sigma$. Between different lag lengths of 1 to 12, the smallest significance probability was chosen. We also applied the test for $e = n^{-0.3}$ ($e = Cn^{-\beta}$ where $C = 1$ and $\beta = 0.3$). The results did not change significantly and were almost the same. We also set the sub-sample at 250 and 400 weeks and then applied all the tests. However, the results were almost similar to when the sub-sample was set at 300 weeks.

3.4 Summary and Conclusion

In this chapter, the rolling window strategy was used to find the linear and nonlinear Granger causality relationship between FFR and 10YGBR during different time horizons and to investigate whether these causalities change with the passing of time. A summary of the current paper is as follows:

In section 1, the main objectives of this chapter were introduced. Then, in section 2, the applied empirical methodology, including rolling window strategy, linear and nonlinear Granger causality tests, was discussed. Explanation about the data sets, the results of unit root tests and the linear and nonlinear Granger causality tests were presented in section 3. In section 4, we combined the linear and nonlinear Granger causality tests results.

According to the findings of the current chapter, the most important conclusions are as follows:

- The linear and nonlinear Granger causality relationships between FFR and 10YGBR are time varying.
- In general, it seems that the linear causality effect of FFR on 10YGBR is increasing with the passing of time.
- The dynamic nonlinear causal relationships between FFR and 10YGBR are almost the same for each bandwidth.
- With the passing of time, the nonlinear causality effect between FFR and 10YGBR are diminishing.

- After combining the linear and nonlinear causality tests results, we found that during different time horizons, there is a significant bidirectional Granger causality relationship between FFR and 10YGBR.

Although we have a different interpretation of the existence of two-way causation between FFR and 10YGBR, this last conclusion provides some support to Pollin (2008). However, while he believes that with the passing of time the Granger causality effect of FFR on market rates becomes insignificant, our results do not support this claim.

In his paper, Pollin only applied the linear Granger causality test, while in the second and third chapters of this thesis we found that considering nonlinear causations between two interest rates are also necessary. Even if we only consider linear Granger causality effects between FFR and 10YGBR, our findings show that there is a significant linear Granger causality from FFR to 10YGBR during much of the recent periods.

General Conclusions

In the first and second chapters of the thesis, we tried to find causality relationships between the federal funds rate and the overnight rate on one hand, and five different interest rates on the other hand, during the last seven business cycles in the U.S. and during the last three business cycles in Canada. The results showed that researchers should be aware of the weaknesses of the standard linear Granger causality test to detect all the causality relationships between interest rates.

To find the linear and nonlinear causality effects between interest rates, the Toda-Yamamoto approach and the Diks-Panchenko nonparametric method were applied respectively. The results showed that the linear Granger causality tests have some weaknesses in finding all the causality effects between interest rates and there was some evidence that nonlinear Granger causality effects could be detected, whereas the linear ones could not be found.

After combining the linear and nonlinear Granger causality test results, we saw that during the related periods in the U.S. and Canada, the most common Granger causality direction between the federal funds rate and overnight rate with the other interest rates was a bidirectional one.

Our findings about the causality directions during recent business cycles were in contradiction with what had been found by some post-Keynesian structuralists like Pollin (2008). Pollin, without considering nonlinear causality effects and solely based on the linear Granger causality test, concludes that, recently, the federal funds rate cannot cause long-term interest rates significantly. He also concludes that the significant two-way Granger causality between the federal funds rate and long-term interest rates has been diminishing over the more recent business cycles. Therefore, according to his belief, the central banks' power to exogenously determine market rates (except the prime rate) is ever more limited. Even our results from linear causality tests did not confirm Pollin's belief, as we showed that the federal funds rate appeared to linearly cause the long-term interest rates significantly during recent business cycles.

In the last chapter, the rolling window strategy was employed to detect the linear and nonlinear Granger causality relationship between the federal funds rate and the 10-year government bond rate, during different time horizons, investigating whether these causalities change with the passing of time. After combining the linear and nonlinear causality test results, we found that during different time horizons, there is a significant two-way Granger causality relationship between these interest rates. Although we have a different interpretation of the existence of bidirectional causation between these two interest rates, this conclusion provides some support to Pollin (2008). However, while he believes that with the passing of time the Granger causality effect of the federal funds rate and market rates becomes insignificant, our results once again do not support this claim.

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Computer Codes

To obtain the results that are presented in chapter 2 and 3, some computer codes are used. These codes are as follows:

STATA Codes to Obtain the Best Lag Length for Estimating VAR Models and Applying the linear Granger Causality Test in Rolling Window Strategy:

```
tsset T
capture program drop varaiccomb
program varaiccomb, rclass
version 12.0
syntax varlist [if] [in]
marksample touse
qui tsset
local timevar  "`r(timevar)'"
tsset `timevar'
varsoc `varlist' if `touse', maxlag(P)
matrix lagres = r(stats)
matrix aiclags=lagres[1...,"lag"]
matrix aicstat=lagres[1...,"AIC"]
capture drop aiclagsvari1 aicstatvari1
svmat aiclags, names(aiclagsvari)
svmat aicstat, names(aicstatvari)
sort aicstatvari1
scalar smalllag= aiclagsvari1[1]

tsset
local locsmallag = smalllag
var `varlist' if `touse', lags(1/`locsmallag')
vargranger
matrix pvres = r(gstats)
matrix pvs1= pvres[1,"p"]
scalar scpv1=pvs1[1,1]
matrix pvs2= pvres[3,"p"]
scalar scpv2=pvs2[1,1]
return scalar pvalue1  = scpv1
return scalar pvalue2  = scpv2
return scalar bestaic  = smalllag
end
rolling firstpvalue=r(pvalue1) secondpvalue=r(pvalue2) aicgoodlag=r(bestaic), window(M):
varaiccomb FFR 10YGBR
varsoc FFR 10YGBR
```

Note: P is the maximum lag length of the VAR model and M is the sub-sample length.

C Codes to Obtain the Residuals of the VAR models in Rolling Window Strategy:

```
#ifndef GARCH_LL
#define GARCH_LL
#define abs(a) (a)<0 ? -(a) : (a)

Matrix VAR (int k, int M, int p, Matrix& data) //Estimate a VAR(1) model
{//k is the step size; M is the subsample size; p is the autoregression order;
 Matrix X(M,1), X1(1,2*p+1), Y(M,1), Q(2*p+1,2*p+1), P1(2*p+1,1), P2(2*p+1,1);

for (int i = k+1; i <= M+k; i++)
 {
     X(i-k) = data(i,1);
     Y(i-k) = data(i,2);
 }
 X1(1,1) = 1;
 int j, el;
 Q.set(0.);
 P1.set(0.);
 P2.set(0.);
 for (int i = p+1; i <= M; i++)
 {
    j = 2;
    el = 1;
    do
    {
       X1(1,j) = X(i-el);
       X1(1,j+1) = Y(i-el);
       j += 2;
       el += 1;
    }
    while((j < 2*p +1)&&(el <= p));
    Q = Q + Tr(X1)*X1;
    P1 = P1 + X(i)*Tr(X1);
    P2 = P2 + Y(i)*Tr(X1);
 }
 Matrix Tau1(2*p+1,1), Tau2(2*p+1,1), res(M-p,2);
 Tau1 = inv(Q)*P1; //estimates of the VAR coefficients
 Tau2 = inv(Q)*P2; //estimates of the VAR coefficients
 for (int i = p+1; i <= M; i++)
 {
    res(i-p,1) = X(i) - mulvec(X1,Tau1); //output the residuals
    res(i-p,2) = Y(i) - mulvec(X1,Tau2);
 }
 return res;
}
#endif
```

C Codes for Nonlinear Granger Causality Test[1]:

```
// Code for T test statistics for Granger causality test
// 23/04/2005

// optimized for Linux

// for comments/suggestions please contact Valentyn Panchenko v.panchenko@uva.nl
#ifndef GCTtest
#define GCTtest
#include <stdio.h>
#include <stdlib.h>
#include <math.h>
#define max(a,b)          a>b?a:b

double T2,*h;

//returns T2 statistics
void redun(double *x, double *y, int N, int m, int mmax, double
epsilon)
{

  int i, j, s;
  int IYij, IXYij, IYZij, IXYZij;
  double disx, disy, disz, *Cy, *Cxy, *Cyz, *Cxyz, mu;

  mu=pow(2.0*epsilon,m+2*mmax+1);

  Cy = (double *) malloc(N*sizeof(double));
  Cxy = (double *) malloc(N*sizeof(double));
  Cyz = (double *) malloc(N*sizeof(double));
  Cxyz = (double *) malloc(N*sizeof(double));

  for (i=0;i!=N;i++)
    h[i] = Cy[i] = Cxy[i] = Cyz[i] = Cxyz[i] = 0.0;

  T2=0.0;

  for (i=mmax;i!=N;i++)
  {
    Cy[i]=Cxy[i]=Cyz[i]=Cxyz[i]=0.0;
    for (j=mmax;j!=N;j++)
    if (j!=i)
```

[1] - This part of codes is written by Valentyn Panchenko and is obtained from Valentyn Panchenko's research website: http://research.economics.unsw.edu.au/vpanchenko/

```
 {
   disx = disy = 0.0;
   for (s=1;s!=m+1;s++)
     disx = max(fabs(x[i-s]-x[j-s]),disx);

   for (s=1;s!=mmax+1;s++)
     disy = max(fabs(y[i-s]-y[j-s]),disy);

   if (disy <= epsilon)
   {
        Cy[i]++;

     if (disx <= epsilon)
     {
       Cxy[i]++;
     }

     disz = max(fabs(y[i]-y[j]),disy);
     if (disz <= epsilon)
     {
       Cyz[i]++;
       if (disx <= epsilon)
       {
         Cxyz[i]++;
       }
     }
   }  // end condition |Yi - Yj| < epsilon
 }  // end loop over j

 Cy[i] /= (double)(N-mmax);
 Cxy[i] /= (double)(N-mmax);
 Cyz[i] /= (double)(N-mmax);
 Cxyz[i] /= (double)(N-mmax);

 h[i] += 2.0/(double) mu*(Cxyz[i]*Cy[i] - Cxy[i]*Cyz[i])/6.0;
}

for (i=mmax;i!=N;i++)
{
 for (j=mmax;j!=N;j++)
 if (j!=i)
 {

   IYij = IXYij = IYZij = IXYZij = 0;
   disx = disy = 0.0;

   for (s=1;s!=m+1;s++)
     disx = max(fabs(x[i-s]-x[j-s]),disx);
```

```
    for (s=1;s!=mmax+1;s++)
      disy = max(fabs(y[i-s]-y[j-s]),disy);

    if (disy <= epsilon)
    {

      IYij=1;
      if (disx <= epsilon)
              IXYij = 1;

      disz = max(fabs(y[i]-y[j]),disy);
      if (disz <= epsilon)
      {
              IYZij = 1;
        if (disx <= epsilon)
          IXYZij = 1;
      }
    }   // end condition |Yi - Yj| < epsilon

    h[i] += 2.0/(double) mu*(Cxyz[j]*IYij + IXYZij*Cy[j] - Cxy[j]*IYZij - IXYij*Cyz[j])/(double)(6*(N-
mmax));
   }   // end second loop over j
 } // end loop over i

 for (i=mmax;i!=N;i++)
   T2 += h[i];

 T2 /= (double)(N-mmax);
 for (i=mmax;i!=N;i++)
    h[i] -= T2;


 free (Cy);
 free (Cxy);
 free (Cxyz);
 free (Cyz);

}

void InsertionSort(double *X, int *S, int M)
{
   int i, *I;
   int j;
   int r;
   double R;

   I= (int*) malloc (M*sizeof(int));
```

```
   for (i=0;i<M;i++)
     I[i]=i;

   for (i=1; i<M; i++)
     {
       R = X[i];
       r = i;
            for (j=i-1; (j>=0) && (X[j]>R); j--)
       {
              X[j+1] = X[j];
         I[j+1] = I[j];
       }
            X[j+1] = R;
       I[j+1] = r;
     }
   for (i=0; i<M; i++)
     S[I[i]]=i;

}


void  uniform (double *X, int M)
{
  int *I, i;

  I = (int*) malloc (M*sizeof(int));
  InsertionSort(X, I, M);

  for (i=0;i<M;i++)
    X[i] = (double) I[i]/M*3.464101615;       // to make unit variance

}

/* normalize the time series to unit std. dev. */

void normalise(double *x, int N)
{
  int i;
  double mean=0.0, var=0.0;

  for (i=0;i!=N;i++)
  {
    mean += x[i];
    var += x[i]*x[i];
  }

  mean /= (double)(N);
```

```
  var /= (double)(N);
  var -= mean*mean;

  for (i=0;i!=N;i++)
    x[i] = (x[i]-mean)/sqrt(var);

  return;
}
```

Matrix GCT (Matrix& data, int m, double epsilon)//m is the embedding dimension, epsilon is the bandwidth

```
{
  double *x, *y, VT2,  p_T2, p_T21, *ohm, *cov, T2_TVAL, T2_TVAL1;
  int i, j, l, k, K, N;
  N = data.nRow();

  x = (double *) malloc(N*sizeof(double));
  y = (double *) malloc(N*sizeof(double));

  h = (double *) malloc(N*sizeof(double));

  K = (int)(sqrt(sqrt(N)));
  ohm = (double *) malloc(K*sizeof(double));
  cov = (double *) malloc(K*sizeof(double));

  for (i=0;i<N;i++)
  {
    x[i] = data(i+1,1);
    y[i] = data(i+1,2);
  }

  normalise(x,N);
  normalise(y,N);
  redun(y,x,N,m,m,epsilon);

  ohm[0] = 1.0;

  for (k=1;k<K;k++)
    ohm[k] = 2.0*(1.0-k/(double)(K));

  /* determine autocovariance of h[i] */

  for (k=0;k!=K;k++)
  {
    cov[k] = 0.0;
    for (i=m+k;i!=N;i++)
      cov[k] += h[i]*h[i-k];
```

```
    cov[k] /= (double)(N-m-k);
  }

  T2_TVAL=VT2=0.0;

/* variance of T2 */

  for (k=0;k!=K;k++)
    VT2 += 9.0*ohm[k]*cov[k];

  T2_TVAL = T2*sqrt(N-m)/sqrt(VT2);

  p_T2 = 0.5 - .5*erf(T2_TVAL/sqrt(2.0));
  Matrix res(2,1);
  res(1) = T2_TVAL; //return T statistics
  res(2) = p_T2; //return p-values
  return res;
}
#endif
```

C Codes for Nonlinear Granger Causality Test on the Residuals Obtained from the VAR models in Rolling Window Strategy

```
#include <iostream>
#include <fstream>
#include <iomanip.h>   // format manipulation
#include <string>
#include <cstdlib>
#include <math.h>
#include <cmath>
#include <vector> // C++ vector class
#include <algorithm>
#include <functional>
#include <gsl/gsl_randist.h>
#include <gsl/gsl_rng.h>
#include <matrix_ops1.h>
#include <filein.h>
#include <limits>
#include <VAR.h>
#include <GCTtest.h>

using namespace std;

//void (*aktfgv)(double *,double *,int *,int *,void *,Matrix&);

int main(void) {
```

```
  char infil1name[128]="x.txt",infil2name[128]="y.txt",
outfilname[128]="test1.txt",outfilname1[128]="test2.txt",outfilname2[128]="test3.txt",outfilname3
[128]="test4.txt";
  cout<<"enter infil1name:";
  cin>>infil1name;
  cout<<endl<<"enter infil2name:";
  cin>>infil2name;
  cout<<endl;

ifstream abscissae;
 abscissae.open(infil1name, ios::in);//put the data file here.
 if (!abscissae)
    return(EXIT_FAILURE);
 vector<string> data1;
 loadCSV(abscissae, data1);
 int N2 = data1.size(); //Rows
 Matrix u(N2,1);
 for (int i = 1; i <= N2; i++)
 {
     u(i) = hex2d(data1[i-1]);
 }
 abscissae.close();

  ifstream abscissae1;
 abscissae1.open(infil2name, ios::in);
 if (!abscissae1)
    return(EXIT_FAILURE);
 vector<string> data2;
 loadCSV(abscissae1, data2);
 int N3 = data2.size(); //Rows
 Matrix v(N3,1);
 for (int i = 1; i <= N3; i++)
 {
     v(i) = hex2d(data2[i-1]);
 }
 abscissae1.close();


 int m = 12, k = 1, M; /*m is the embedding dimension; k is the step size; M is the subsample size <
the sample size, p is the number of lags in the VAR model*/

  cout<<endl<<"enter M:";
  cin>>M; //= 300;
  double epsilon; //bandwidth=1.5;
  cout<<endl<<"N3-M is  "<<N3-M<<"   --Make sure lag contains this number of items.--";
  cout<<endl<<"enter epsilon:";
  cin>>epsilon;
```

```
Matrix data(N3,2);
for (int i = 1; i <= N3; i++)
{
   data(i,1) = u(i);
   data(i,2) = v(i);
}

Matrix res(2,1);
Matrix p(N3-M,1);

ifstream abscissaeLag;
  char infilLag[128]="lag.txt";
abscissaeLag.open(infilLag, ios::in);//put the data file here.
if (!abscissaeLag)
   return(EXIT_FAILURE);

vector<string> data_lag;
loadCSV(abscissaeLag, data_lag);
int NLag = data_lag.size(); //Rows
for (int i = 1; i <= N3-M; i++)   //the input file must have N3-M entries
{
    p(i) = hex2d(data_lag[i-1]);
}
abscissaeLag.close();

for (int i = 1; i <= N3-M; i++)   //the input file must have N3-M entries
{
    cout<<"p(i)="<<p(i)<<"\n";
}

//define and open output, step 1
FILE *outfil,*outfil1;
if ((outfil=fopen(outfilname,"w")) == NULL) outfil=stdout;
else printf("The results are saved to the file: %s\n",outfilname);
if ((outfil1=fopen(outfilname1,"w")) == NULL) outfil1=stdout;
else printf("The results are saved to the file: %s\n",outfilname1);
fprintf(outfil,"T statistics\n");
fprintf(outfil,"res x on y:  %s on %s \n",infil1name,infil2name);
fprintf(outfil1,"p-value\n");
fprintf(outfil1,"res x on y:  %s on %s \n",infil1name,infil2name);

do
{     Matrix Residual(M-(int)p(k),2);
      Residual = VAR (k, M, (int)p(k), data);
      res = GCT (Residual, m, epsilon);
      cout << res(1) << "," << res(2) << endl;

      //Print to the output, step 2
```

```
      fprintf(outfil,"%.3f\n",res(1));
      fprintf(outfil1,"%1.5f\n",res(2));

         k += 1;
 }
 while(k <= N3-M);

 // close output, step 3
 _fcloseall();

  //Matrix data(N3,2);
 m = 12, k = 1;
 for (int i = 1; i <= N3; i++)
 {
    data(i,1) = v(i);
    data(i,2) = u(i);
 }

 //Matrix Residual(M-p,2), res(2,1);

 //define and open outpu, step 1
 //FILE *outfil,*outfil1;
 if ((outfil=fopen(outfilname2,"w")) == NULL) outfil=stdout;
 else printf("The results are saved to the file: %s\n",outfilname);
 if ((outfil1=fopen(outfilname3,"w")) == NULL) outfil1=stdout;
 else printf("The results are saved to the file: %s\n",outfilname1);
 fprintf(outfil,"T statistics\n");
 fprintf(outfil,"res y on x:  %s on %s \n",infil2name,infil1name);
 fprintf(outfil1,"p-value\n");
 fprintf(outfil1,"res y on x:  %s on %s \n",infil2name,infil1name);

do
 {     Matrix Residual(M-(int)p(k),2);
      Residual = VAR (k, M, (int)p(k), data);
      res = GCT (Residual, m, epsilon);
      cout << res(1) << "," << res(2) << endl;

      //Print to the output, step 2
      fprintf(outfil,"%.3f\n",res(1));
      fprintf(outfil1,"%1.5f\n",res(2));
          k += 1;
 }
 while(k <= N3-M);
  // close output, step 3
 _fcloseall();
  system("PAUSE");
  return 0;
}
```