The Impact of U.S. Uncertainty on the Canadian Economy in Recession and Expansion

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ABSTRACT

Economic uncertainty is an important factor that affects decisions made by households, policy makers and enterprises. Very few studies focus their attention on the importance of uncertainty in Canada. This thesis attempts to bring attention and insight to the topic of the effects of macroeconomic uncertainty. I address this issue for the Canadian economy by using the U.S. Economic Policy Uncertainty (EPU) index in a Vector Autoregressive (VAR), and a Markov-Switching Vector Autoregressive (MS-VAR) framework, allowing the intercept to switch across two regimes: expansion and recession. I investigate the impact of a U.S. and Canadian uncertainty shock on the Canadian economy, and compute impulse responses allowing for regime switches after the initial shock.

First, I find that in a standard VAR that includes the U.S. EPU index and the Canadian GDP, a unitary uncertainty shock decreases the Canadian GDP. The second finding further reveals that the impact of uncertainty is asymmetric between expansions and recessions. In the MS-VAR model, when economic agents are aware of the possibility of regime changes, a unitary uncertainty shock decreases the Canadian GDP 8 times more in the recession regime compared to the expansion regime. I also find that a Canadian uncertainty shock in the VAR model has a weaker effect on GDP than a U.S. shock. In the MS-VAR model, the impact of the shock differs between the two regimes; the effect on Canadian uncertainty shock in the recession regimes is similar to a U.S. uncertainty shock. Nevertheless, the effect of an uncertainty shock is milder in the expansion regime. Understanding asymmetric propagation of uncertainty is crucial for policymakers and economic agents, as the effect of uncertainty is asymmetric dependent upon whether the economy is in recession or expansion.

Keywords: Economic Policy Uncertainty Index, Vector Autoregression, Markov-Switching Vector Autoregression, Regime Switching, Uncertainty Shock, Unconditional Impulse Responses.

RÉSUMÉ

La place de l'incertitude dans l'économie est un facteur important pour les ménages, les décideurs politiques et les entreprises. Peu d'études se concentrent sur l'importance de l'incertitude au Canada. Ce papier comble un vide et apporte des réponses dans la littérature. L'incertitude peut être quantifiée avec l'Indice d'Incertitude de la Politique Économique (EPU) des États-Unis dans un modèle de Vecteur Autorégressif (VAR) et dans un modèle de Vecteur Autorégressif à Changements de Régimes Markovien (MS-VAR) permettant à l'intercepte de changer entre les régimes d'expansion et de récession. Nous cherchons à connaître l'impact d'un choc d'incertitude des États-Unis et Canadien sur l'économie canadienne. Nous utilisons des réponses impulsionnelles permettant un changement de régime après le choc initial afin de répondre aux différentes questions.

Premièrement, nous trouvons que dans un VAR comprenant les variables : U.S. EPU et le PIB canadien, l'impact d'un choc d'incertitude des États-Unis diminue le PIB canadien. Notre second résultat démontre que l'impact d'incertitude est asymétrique entre le régime d'expansion et de récession. Dans notre modèle MS-VAR, lorsque les agents économiques sont conscients d'une possibilité de changement de régime, un choc d'incertitude diminue 8 fois plus le PIB canadien dans le régime de récession que celui d'expansion.

Enfin, nous trouvons que l'effet d'un choc d'incertitude canadien dans un modèle VAR a un effet plus petit sur le PIB qu'un choc d'incertitude provenant des États-Unis. Dans le modèle MS-VAR, l'impact du choc est différent entre les deux régimes. L'effet d'un choc d'incertitude canadienne dans le régime de récession est similaire à celui des États-Unis. Néanmoins, ce dernier est moindre dans le régime d'expansion. Comprendre l'asymétrie de la propagation de l'incertitude est crucial pour les décideurs politiques et les agents économiques, car les effets de l'incertitude sont asymétriques dépendamment si l'économie est en récession ou en expansion.

Mots clés: l'Indice d'Incertitude de la Politique Économique, Vecteur Autoregressif, Vecteur Autorégressif à Changements de Régimes Markovien, Choc d'incertitude, Réponse impulsionnelle inconditionnelle.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

VAR:	Vector Autoregression
SVAR:	Structural Vector Autoregression
MS-VAR	Markov Switching Vector Autoregression
MSI(2)-VAR(1)	Markov Switching Vector Autoregression allowing only the intercept to switch across regimes with 2 regimes and 1 lag
MS-SVAR	Markov Switching Structural Autoregression
EPU:	Economic Policy Uncertainty (Index)
GDP:	Gross Domestic Product
AIC:	Akaike Information Criterion
BIC:	Bayesian Information Criterion
HQ:	Hannan-Quinn (information criterion)
IRF:	Impulse Response Function
VIX:	CBOE Volatility Index

I. INTRODUCTION

In the globalized world of integrated markets, the transmission of uncertainty can be seen as the result of the butterfly effect. One financial or economic crisis can rapidly spread to the other side of the world in a matter of seconds. Li & Willett (2012) and Tuca (2014) underline that the modern world economy is so deeply interlinked, that one shock will spread instantaneously to the real economy.

In recent years, many papers have focused on the impact of uncertainty on the economy both at the micro and macro economic level. The role of uncertainty, both in finance and in macroeconomics, has taken a larger place in the literature. Uncertainty affects the behaviour and the decisions of firms, households, and decision makers. Macroeconomics experts have tried to understand the effects and role of uncertainty on the business cycle. Most papers focus their attention on the U.S., the U.K., and the Eurozone; these papers investigate the impact of a U.S. uncertainty shock on the Canadian economy.

Economists have tried to model the abstract notion of uncertainty through various proxies. The two most well-used variables used are the Volatility Index (VIX), based on the implied volatility measuring the expectations of the stock market, and the Economic Policy Uncertainty index (EPU). The former is based on the S&P 500 index options market in the U.S. The latter was first developed by Baker, Bloom and Davis (2012), and (2016). They introduced a new index of economic policy uncertainty based on newspaper coverage frequency. This proxy for uncertainty is used by many contemporary papers to study the importance of uncertainty for macroeconomic dynamics. In this thesis, we use the U.S. EPU to measure the impact of a U.S. uncertainty shock. Other alternatives exist as confidence indicators, sentiment indicators, indices based on now cast and forecast error distributions, and indexes from option prices.

Extensive work has been undertaken by Bloom (2009), Columbo (2013), Cheng & Wong (2017), Mumtaz and Theodoridis (2012), using linear models to estimate the effect of uncertainty in economies. Authors place uncertainty as a key factor that precedes an economic crisis; results show that an exogenous increase in uncertainty negatively affects the economy. More recently, researchers have begun to use non-linear models to understand the role of uncertainty on the economy. Authors find that uncertainty impacts the economy asymmetrically during recession and expansion. Few papers use non-linear models to investigate the role of uncertainty in the Canadian economy. For instance, Caggiano and Castelnuovo (2017) use the U.S. EPU with a Smooth Transition Vector AutoRegression (STVAR) to find strong evidence of asymmetric spillover effects of U.S. uncertainty on unemployment in Canada. The authors establish that a small open economy such as Canada is influenced by large open economies such as the United States. This argument explains the use of U.S. EPU as their proxy for U.S. uncertainty in investigating the effect of peaks on Canadian unemployment.

The objective of this thesis is to extend this line of research, analyzing the spillover effect of U.S. uncertainty on the Canadian economy. The primary contribution of this thesis is the estimation of the impact of U.S. uncertainty using a VAR to confirm previous work, and a MS-VAR allowing only the intercept to switch between regimes. To the best of our knowledge, the second contribution has never been done for Canada. We measure the impact of a U.S. uncertainty shock using unconditional impulse responses on the Canadian economy, allowing for regime switches after the initial shock. The last contribution is the comparison of a U.S. and Canadian uncertainty shock on the Canadian economy using the Canadian EPU index with a traditional VAR and a MS-VAR. This variable is constructed in a similar manner than the U.S. EPU using Canadian newspapers.

How does U.S. uncertainty affect the Canadian economy? Are the effects different during recessions and expansions?

To answer these questions, we estimate two reduced-form Vector Autoregressive (VAR) models. The first VAR includes the U.S. EPU and the Canadian GDP; the second VAR also includes the Canadian Bank Rate and the Canadian CPI. We then impose a recursive ordering (e.g. Cholesky decomposition) on the two VARs to recover the parameter from the Structural Vector Autoregressive (SVAR) model. Then, we compute impulse responses to measure the effect of U.S. uncertainty shock on the Canadian economy.

In a second step, we employ a Markov-switching vector autoregressive (MS-VAR) framework, allowing only the intercept to switch between the regimes. We only include the U.S. EPU and the Canadian GDP. We use the same identification strategy, the Cholesky decomposition. We then compute the unconditional impulse responses to measure the magnitude of the U.S. uncertainty shock in the recession and expansion regimes, allowing any shift in regimes after the initial impact. We also compare the findings between the two frameworks.

Finally, we conduct the same exercise by replacing the U.S. EPU with the Canadian EPU.

The analysis yields three main results. First, the results of the linear model corroborate previous work undertaken in Canada. The U.S. uncertainty has a significant impact on the Canadian economy; a rise of uncertainty significantly decreases the Canadian GDP.

The second, and arguably most important finding, confirms work completed mainly in the United States, the United Kingdom, and the Eurozone. The impact of U.S. uncertainty does indeed depend on the regime. The shock affects the Canadian economy more strenuously during a recession than during an expansion.

Finally, we find that the effect of a Canadian uncertainty shock is similar to a U.S. uncertainty shock, but the effect is smaller in the linear VAR. Concerning the unconditional impulse responses from the MS-VAR, the effect of Canadian and U.S. uncertainty is similar in the recession regimes. For the expansion regimes, the Canadian uncertainty has a smaller effect on the economy. Surprisingly, the recovery time after the initial Canadian uncertainty shock is always longer.

The remainder of this thesis is organized as follows: Section 2 provides a contribution to the literature and the motivation behind it; we introduce the literature review concerning nonlinear models and empirical investigations of uncertainty in previous studies. Section 3 presents the VAR and the MS-VAR frameworks we use to capture the dynamic and the relationship between variables; we also explain the mathematical background of the unconditional impulse responses. Section 5 discusses the choice of variables we use and the transformation we applied to the different time series. Section 6 examines the results found in this thesis. Finally, Section 7 provides some concluding remarks.

II. LITERATURE REVIEW

Introduction

Understanding the effect of uncertainty on the economy is important for economic agents in order to successfully forecast their decisions. As explained in the introduction, the effects of uncertainty do affect the behaviour of firms, households, and decision makers. Theoretical work has been done in the past, prior to the year 2000: Bernanke (1983) and Dixit & Pindyck (1994). Since then, more researchers pay attention to empirical studies to better understand the role of uncertainty in the economy.

Several peaks of uncertainty have been observed around the world through economic, financial and political events. Local, regional or global increases and decreases of uncertainty have been noticed. Since the early 2000’s, policy makers have focused their work to understand the effect of uncertainty in the economy. The integration and globalization of the market has increased the rapidness of the crisis.

In the last thirty years, numerous events have brought dramatic peaks of uncertainty to Canada at global and local scales of the economy. The commodity slump price, elections in the United States and Europe, the Eurozone crisis, the Great Recession, the September 11 attacks, the dot-com bubble, and state-conflict have spiked worry and anxiety in the economy. Canada is economically dependent on the United States due to its strong interconnection; the rate of export to the United States is 76% for the Canada in 2017, representing 19.35% of the Canadian GDP. In 2017, 53% of total Canadian imports came from the United States. The Canadian economy is a small and open economy, neighbouring the largest economy in the world. Caggiano and Castelnuovo (2017) state that to measure the impact of uncertainty in a small open economy, researchers should focus on a large open economy with an economic link. Policy decisions and economic fluctuations from the United States strongly affect small open economies and the decisions of policymakers in Canada.

Figure 1 details 14 drastic increases of uncertainty measured by the U.S. EPU between 1985 and 2017. In examining the 32 years of data available, we can observe that these peaks are grouped into four main categories: politics, economics, financial, and conflict.

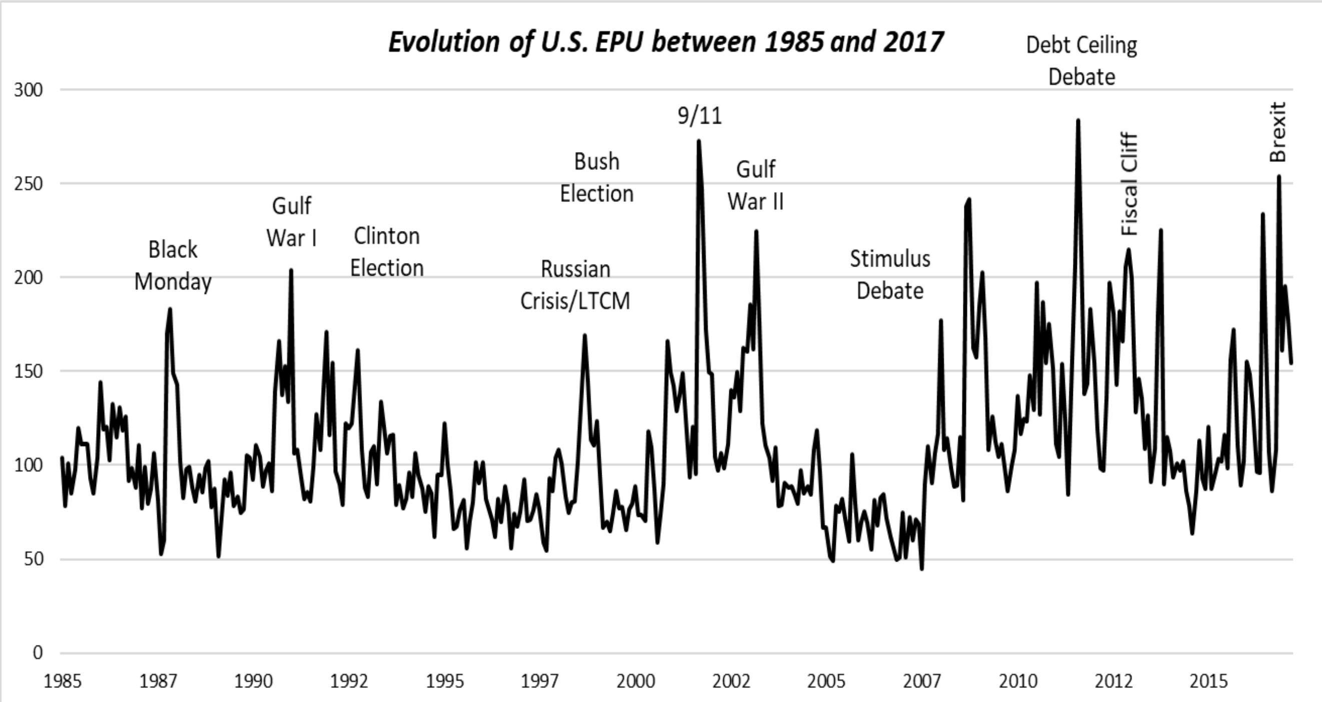

Figure 1: Evolution of U.S. EPU between 1985 and 2017

The Theoretical Role of Uncertainty

The conceptualization of uncertainty in economic theory has been theoretically developed in order to understand its role in the economy. Bernanke (1983) provides a theoretical framework for explaining how uncertainty impacts an investment decision. The author points out that the cost of waiting for new information exists and delays the current rate of investment. He notes that economic agents defer their investment, therefore bringing a decrease in current investment; this underinvestment and wait-and-see attitude could explain the business cycle.

In the theory literature, Dixit and Pindyck (1994) showed that in investment decisions, economic agents consider the importance of uncertainty. They define three variables that firms encountered: sunk costs about investment, uncertainty regarding future returns, and the right timing of investing. This paper underlines that in a high uncertainty period, the optimal decision for firms to make irreversible investment is to wait for more information. They show that firms should assess probabilities of different outcomes in order to make investment decisions.

More recently, Bloom, Floetotto, and Jaimovich (2009) conclude that recessions are primarily driven by uncertainty. In normal times, firms face a non-convex adjustment cost because of noncontinuously investing. As such, when higher volatility in uncertainty arises, it implicates an under-investment approach by firms, therefore directly impacting productivity and creating a wait-to-see attitude. Moreover, they argue that total productivity factors (TPF) decrease substantially during high periods of uncertainty. Firms defer their projects' investment until the expectation of a better economy arrives. The increase and volatility of uncertainty immobilizes firms' decisions and pushes them to adopt a non-reactive attitude. Empirical research has characterized the slow recovery after a recession and shows that decision-makers have an aversion to uncertainty.

Bloom (2009) confirms that investment and hiring behaviour change when uncertainty increases; when the economic environment is uncertain, the optimal decision for an investment or hiring is postponed until the business condition becomes better. The author points out that uncertainty shocks change the behaviour of economic agents. He concludes that this inaction results in a decline in productivity growth.

The actual environment of the economy and its future is an important key for decisions both at the firm and household level. Firms and households postpone their investment and adopt wait-and-see attitudes in waiting for a better forecast of the economy. The postponement of decisions has macro consequences. These theoretical works have been verified by empirical works.

Linear Empirical Approaches

Bloom (2009) estimates a VAR, and takes as a proxy for uncertainty the U.S. stock market volatility. He finds strong evidence of the negative responses on output, employment and productivity in the presence of an increase in uncertainty. Colombo (2013) extends his work and examines the spillover effect of U.S. uncertainty on the Eurozone, examining that a rise in uncertainty leads to a drop in industrial production and prices in the Eurozone. Similar research has examined the international transmission of uncertainty shocks. Mumtaz and Theodoridis (2012), for instance, investigate the international transmission of uncertainty using the second moment shock from the U.S. to U.K. They find that U.K. GDP declines and the CPI inflation increases after a U.S. volatility shock. In the same field of study, Luk, Cheng and Wong (2017) show that a small open economy that based its GDP on international trade is impacted by the uncertainty of major trade partners, such as the Eurozone, Mainland China, and Japan.

The literature agrees on the role of uncertainty in the economy. Authors show that an uncertainty shock negatively affects the economy; uncertainty from large open economies has a significant impact on small open economies.

Using a linear model brings some questions about the assumptions made on these models, however. The business cycle is characterized by a long phase of expansion and sudden crisis over the time. In order to model these drastic changes or breaks, there is a growing literature focusing on using non-linear models.

Non-linear Empirical Approaches

The non-linear approach has grown in popularity in recent years. Theoretical and empirical work has shown the limitation of the linear models in estimating the business cycles.

In the macroeconomics literature, the contribution of the univariate Markov switching model proposed by Hamilton (1989) has instigated a new branch of the economy; he improved upon the work of Goldfeld and Quandt (1972). Hamilton's work uses time-varying parameter models in macroeconomics and finance research. Macroeconomists have developed the Markov switching model, allowing the identification of different regimes in a model. Krolzig (1997b) and Krolzig (1998) developed Hamilton's work and proposed a multivariate MS-VAR, therefore allowing for more flexibility.

The MS-VAR framework is now broadly used by researchers. Lhuissier and Tripier (2016) use a Markov switching model to capture uncertainty shocks in the U.S. economy. The authors use the VIX and the credit spread as proxies for uncertainty in order to measure the impact on GDP in periods of expansions and recessions. The model allows for understanding the asymmetric effects of uncertainty in different regimes where economic agents are aware of the possibility of a switch. They find that the coefficiency of GDP changes in variance and also in means; a 10% increase in the VIX index results in a decline of 1% in output in the regime of financial crisis, but the effect is nearly non-existent in the tranquil regime.

Netšunajev and Glass (2017) use a MS-VAR in the variance of shocks. They study the cross effects of uncertainty shocks in U.S. and Euro areas on unemployment. Their contribution to the literature underlines that both local and international uncertainty has a negative spillover impact on employment. They also find that an increase in uncertainty in the U.S. affects the labour market directly in the Eurozone. Their results support more arguments that uncertainty has a tangible impact on the real economy through unemployment.

Caggiano and Castelnuevo (2017) investigate the spillover effect of U.S. uncertainty on the Canadian economy during recessions and expansions. In their study, they use a non-linear STVAR model, finding strong evidence of an asymmetric spillover of a U.S. uncertainty shock on Canadian unemployment.

Following their work, we use a MS-VAR model to investigate the effect of uncertainty shocks in different regimes, allowing the regimes to switch after the initial impact.

Unconditional Impulse Responses

In order to compute impulse responses with a MS-VAR model, two research branches exist; one developed by Ehrmann, M., Ellison, M. & Valla, N. (2003). They develop a regime-dependent impulse response function in a MS-VAR. The effect of their shock depends on the regimes and is fixed after the initial shock. Moreover, the size of the shock is different across regimes. Economists compute conditional impulse responses when they are interested in studying the prevailing effects in regime-specific features. This approach is useful when economists seek to understand the macroeconomics characteristics and properties in a specific regime.

In this thesis, we take another approach. We are interested in understanding the different behaviour of the economy allowing for further change in regimes after the initial shock. We follow the work of Bachmann and Leist (2013), Bianchi (2016), Karamé (2010), (2012), Karamé and Olmedo (2010) and Krolzig (2006) by using unconditional impulse responses. This impulse response function is calculated conditionally in a given regime, and allows for a regime switch after the initial shock. When forming their expectations, the economic agents are aware that the economy can switch from one state to another. Economic agents are aware that the uncertainty will fluctuate. They are able to observe previous data, taking this information into account in order to inform their expectations. This approach reflects the Markov property of switching regimes.

Contribution to the Literature

Caggiano and Castelnuovo (2017), Alam (2015) studied the effect of uncertainty in the Canadian economy using linear models. Their results converge on the negative impact of uncertainty on the

Canadian economy. The linear framework can have some limitations and strong assumptions about the behaviour of the economy, however. Few papers use non-linear models to measure the impact of uncertainty. Most papers with non-linear models focus their studies on the United States, the U.K., and the Eurozone.

In this thesis, we use VAR and a MS-VAR framework. The former to confirm previous work done in Canada, the latter to compute unconditional impulse responses in order to understand the effect of uncertainty in recession and expansion. We believe that this thesis adds compelling insights and an interesting empirical analysis to the literature.

III. METHODOLOGY

Two different frameworks are used for our analysis. We use a Vector Autoregressive (VAR) and a Markov-Switching Vector Autoregressive (MS-VAR) model. We apply the recursive identification methodology for addressing the problem of identification. We also introduce the mathematical background for the unconditional impulse response functions when considering the possibility of regime changes after the initial shock.

3.1 Vector Autoregressive Model

The VAR model is an econometric tool used to capture the linear interdependencies among a vector of time series. In this thesis, we want to capture the dynamic macroeconomic response of a U.S. uncertainty shock to other economic variables.

3.1.1 VAR Methodologies

First, we estimate a VAR model with the hypothesis that the behaviour of the time series variables is linear. The VAR is a regression system of N-dimensional vectors with a constant and *p* past lags on each of the N variables and with an error term. The reduced form of the model can be written as:

$$Y_t = \mu + \sum_{\mathrm{i}=1}^{p} \emptyset_i Y_{t-\mathrm{i}} + \varepsilon_t \quad \text{with} \qquad i = 1, 2, \dots, p \tag{1}$$

and

$$E\left(\varepsilon_t \varepsilon_j'\right) = \begin{cases} \Omega_\varepsilon & for\ t = j \\ 0 & otherwise \end{cases} \tag{2}$$

$$E(\varepsilon_t) = 0$$

where Y_t is an observed (n×1) vector of time series $[y_1, y_2, \dots, y_n]'$, μ is the (n×1) intercept vector, $\emptyset_i$ is a (n×n) matrix of autoregressive coefficients, ε_t = $[\varepsilon_{1t}, \varepsilon_{2t}, \dots, \varepsilon_{nt}]'$ is a (n×1) of error terms,

Ω_ε is a (n×n) variance-covariance matrix of the residuals. Ω_ε is a symmetric positive definite matrix, p is the number of lags.

In the literature, the correlation of error terms in the VAR framework has been criticized for its non-theoretical approach. Producing impulse responses with correlated error terms is difficult to economically interpret. Their shocks are not considered as pure exogenous shocks.

One solution to avoid this problem is to use a structural vector autoregressive (SVAR) model:

$$Z\,Y_t = Z_0 + \sum_{\mathrm{i}=1}^{p} \mathrm{Z}_i Y_{t-\mathrm{i}} + u_t \qquad \mathrm{i} = 1, \dots, p \tag{3}$$

and

$$E\left(u_t u_j'\right) = \begin{cases} \Omega_u & for\ t = j \\ 0 & otherwise \end{cases}$$

Otherwise:

$$E(u_t) = 0$$

where

$$\emptyset_i = \mathrm{Z}^{-1}\mathrm{Z}_i \qquad \varepsilon_t = \mathrm{Z}^{-1}u_t \qquad \mu = \mathrm{Z}^{-1}Z_0$$

where Z_i is a (n×n) matrix of structural parameters with Z invertible, and u_t is the vector of structural shocks.

It is not possible to directly identify the SVAR model through the parameter estimation of the reduced-form VAR system. We use the Cholesky decomposition of the variance-covariance matrix to impose restrictions on the SVAR model.

3.1.2 Identification through a Cholesky Decomposition

One popular method for identifying an uncertainty shock in a traditional VAR is the recursive identification methodology. For this approach, we first estimate the VAR to find the coefficients μ, $\emptyset_i$ and the matrix variance-covariance Ω_ε. At this point, we cannot recover the coefficient from the SVAR due to an under-identification of parameters.

The matrix Ω_ε is symmetric. The estimation of the matrix variance-covariance Ω_ε of the VAR gives us $[n(n+1)/2]$ parameters while the matrix Z and the matrix Ω_u include[1] N^2. We need to impose $[n(n-1)/2]$ restrictions on the matrix Z to be able to identify the SVAR model.

Following Sims (1980), we orthogonalize the reduced-form residual ε_t. We use the Cholesky decomposition of the variance-covariance matrix Ω_ε to identify the SVAR. We then impose restrictions on the matrix Z to obtain a lower triangular matrix. We use the relation $\varepsilon_t = Z^{-1}u_t$ to recover the parameter of the SVAR.

The identification through the Cholesky decomposition implies that the ordering of the model matters to identify our parameters. The ordering of the variables is crucial and needs to be based on empirical and theoretical economic theory.

We choose to order the first VAR as follows:

- $Y_t = \begin{bmatrix} U.S.EPU \\ Canada\ GDP \end{bmatrix}$

The order of the second VAR:

- $Y_t = \begin{bmatrix} U.S.EPU \\ Canada\ GDP \\ Canada\ BANK\ RATE \\ Canada\ CPI \end{bmatrix}$

The ordering is characterized as follows: U.S. EPU, which is a proxy for the U.S. uncertainty, is ordered first due to the exogeneity of this variable to the Canadian economy. Uncertainty from the United States has a contemporaneous effect on the Canadian economy, but not vice versa. The Canadian economy heavily depends on the U.S. economy; the United States is the largest export and import markets for Canada. Caggiano and Castelnuovo (2017) state that in order to measure the impact of uncertainty in small open economies, we compare it in relation to a large open and influential economy. Colombo (2013) finds strong evidence that the contribution of U.S. uncertainty on the European aggregate is more important than the Euro area uncertainty. The

[1] Matrix Z has $N^2 - N$ parameters and the matrix Ω_u include N parameters for a total of N^2 parameters to estimate

spillover effect of U.S. uncertainty on the Euro area GDP is important. Klößner and Sekkel (2014), identify that the U.S. and the U.K. are responsible for a large portion of the spillovers of uncertainty among six developed countries. They underline that Canada is a net receiver of the spillover from the U.S. and U.K. These papers support the choice of ordering the U.S. uncertainty before the Canadian GDP.

Canadian GDP responds contemporaneously to U.S. uncertainty, but not to bank rate and inflation. The last two variables are lagged from a change in GDP.

The Bank Rate, a proxy for monetary policy, is a lagging indicator of the economy. Policy changes from the Bank of Canada react to the GDP variable. When GDP declines in Canada, we can observe a bank rate decrease in response. On the other hand, when the GDP growth increases, the Bank Rate also increases, preventing potential risks of overheating.

Inflation is ordered last in the VAR because this variable is a lagging indicator of monetary policy. Theoretical and empirical analysis[2] have shown that the peak effect of monetary policy on inflation takes more than a year. It has a contemporaneous effect on all variables.

We extend the analysis by replacing the U.S. EPU variable with the Canadian EPU in the two differing VARs. The Canadian EPU is ordered first. We estimate the same VARs without taking into consideration the U.S. uncertainty. Section 5.3 displays the results of the findings.

The linearity hypothesis between uncertainty and Canadian GDP is strong. With these results, we further this study with a non-linear model. This is the primary focus of this thesis: to estimate a MS-VAR capturing the non-linearity among variables.

3.2 Markov-Switching Vector Autoregressive Model

Following the recent work on the U.S. business cycle by Lhuissier and Tripier (2016) and Netšunajev and Glass (2017), we use the same model to estimate the effect of U.S. uncertainty on the Canadian economy. The MS-VAR framework allows us to capture the non-linear relationship among the variables.

[2] See The Lag from Monetary Policy Actions to Inflation: Friedman Revisited from Batini and Nelson (2001)

The MS-VAR model allows some flexibility concerning the assumptions about parameters (Krolzig (1997b) and Krolzig (1998)). These different specifications allow more or less restrictive specifications to capture the nonlinear dynamics of variables:

- I Markov switching in intercept:
- C Markov switching in autoregressive parameters:
- H Markov switching in heteroscedasticity:

This thesis focuses on the MSI(q)-VAR(p) model. We allow the intercept to switch states between q-states and p-lags. The autoregressive parameters and the variance-covariance matrix are thus similar across regimes. We include only two regimes (q = 2) in the MS-VAR.

There are two primary reasons behind these choices. First is the difficulty of interpretation due to the inclusion of too many parameters switching between the two regimes[3]. The second reason concerns the numerous parameters that are required in order to estimate. Allowing the MS-VAR to switch in autoregressive parameters, heteroscedasticity or multiple regimes can become overwhelming and lead to unstable estimation.

The MSI(q)-VAR(p) model is defined as:

$$Y_t = \mu(s_t) + \sum_{i=1}^{p} \emptyset_i Y_{t-1} + \varepsilon_t, \qquad i = 1, \dots, p \tag{4}$$

$$\varepsilon_t | s_t \sim NID(0, \Omega_\varepsilon)$$

where Y_t is an observed (n×1) vector of time series $[y_1, y_2, \dots, y_n]'$, μ is a (n×1) vector of intercepts, $\emptyset$ is a (n×n) matrix of autoregressive parameters, ε_t = $[\varepsilon_{1t}, \varepsilon_{2t}, \dots, \varepsilon_t]'$ is a (n×1) of error terms, Ω_ε is a (n×n) variance-covariance matrix of errors, s_t is an unobserved state, p is the lag length.

The MS-VAR model uses a Markov Chain. The probability that the state of the process is in a particular regime at time t depends on the probability of the regime at the time t-1. The assumption

[3] Doan, T. (2011). RATS Handbook for Switching Models and Structural Breaks.

behind the model is that the unobservable realization of the regime is governed by a discrete state. The Markov stochastic process is defined as the transition probability from the state i at time t-1 to state j at time *t*:

$$p_{ij} = P(s_t = \ i \mid s_{t-1} = \mathrm{j}), \ \ \sum_{i=1}^{M} p_{ij} = 1 \ \ \forall i, i \ \in \ \{1, \dots, M\} \tag{5}$$

The transition matrix of s_t is:

$$P = \begin{bmatrix} p_{11} & \cdots & p_{1M} \\ \vdots & \ddots & \vdots \\ p_{M,1} & \cdots & p_{MM} \end{bmatrix} \tag{6}$$

First, we estimate the reduced-form of the Markov-switching VAR by maximum likelihood. We find the intercepts μ, the autoregressive parameters $\emptyset_p$, the variance-covariance matrix, the unobserved states (s_t) and the transition matrix P.

In order to produce impulse responses and observe a pure exogenous U.S. uncertainty shock, we face the same identification problem as the VAR model. The values off-diagonal of the variance-covariance matrix Σ_τ are not equal to 0, meaning that the error terms are correlated.

In order to produce impulse responses to measure the dynamic responses on different regimes, we use a Cholesky decomposition of the variance-covariance matrix Ω_ε.

As in the VAR model presented above, we are able to find all of the parameters needed to solve the equation and recover the MS-SVAR. The ordering of the variable is also crucial in the model. We use the same ordering with U.S. uncertainty first and the Canadian GDP last.

We choose to order the first VAR as following:

- $Y_t = \begin{bmatrix} U.S.EPU \\ Canada\ GDP_{,} \end{bmatrix}$

As mentioned above, we also replace the U.S. EPU variable with the Canadian EPU to measure the effect of the Canadian uncertainty shock on its economy.

3.3 Unconditional Impulse Responses

In this thesis, we are interested in implementing unconditional impulse responses to the MS-VAR. The impulse response considers the possibility of a regime change after an initial shock. Following the work of Krolzig (2006), Bachmann and Stefan (2013) and Bianchi (2016), we present the mathematical background for the unconditional impulse-response analysis used in this thesis. We develop a MSI(2)-VAR(1) with only 2 regimes and 1 lag, allowing only the intercept to switch regimes. The following steps describe the procedure used to compute an unconditional impulse response:

Step 1: We estimate the parameters of the MS-VAR coefficient (μ, $\emptyset$, Ω, P).

Step 2: We use Cholesky decomposition for the identification strategy.

Step 3: Using the properties of the Markov chain, the next period h can be computed as follows:

$$E(\xi_{t+h}|\xi_t) = \begin{pmatrix} P(s_{t+h} = RECESSION \mid s_t = RECESSION) & P(s_{t+h} = RECESSION \mid s_t = EXPANSION) \\ P(s_{t+h} = EXPANSION \mid s_t = RECESSION) & P(s_{t+h} = EXPANSION \mid s_t = EXPANSION) \end{pmatrix} = P^h \xi_t \tag{7}$$

where ξ_t is a (2 x 1) state vector $\xi_t \begin{cases} \binom{1}{0}\ if\ s_t = RECESSION \\ \binom{0}{1}\ if\ s_t = EXANSION \end{cases}$

Step 4: We choose an initial state j in which we apply the uncertainty shock: ($s_t = j$). We then compute impulse responses unconditional on switching in a given regime j.

We define:

$$Y^*_{j,t} = (1 - s_t)(\mu_1 + \emptyset_1 Y_{t-1} + \varepsilon^*_{1,t}) + s_t(\mu_2 + \emptyset_1 Y_{t-1} + \varepsilon^*_{2,t}) \tag{8}$$

$$Y_{j,t} = (1 - s_t)(\mu_1 + \emptyset_1 Y_{t-1} + \varepsilon_{1,t}) + s_t(\mu_2 + \emptyset_1 Y_{t-1} + \varepsilon_{2,t})$$

where $\varepsilon^{*}{}_{j,t} = \mathrm{Z}_i^{-1} u_t^*$ is the reduced form residual of the regime and u_t^* is the structural shock. At impact, the unobserved state (s_t) takes the value of 0 and 1. The unconditional impulse response on impact is given by:

$$IRF_{j,t} = Y_{j,t}^* - Y_{j,t} = \begin{cases} \varepsilon_{1,t}^* - \varepsilon_{1,t} & if\ j = RECESSION \\ \varepsilon_{2,t}^* - \varepsilon_{2,t} & if\ j = EXPANSION \end{cases} \tag{9}$$

The unconditional impulse responses after the initial impact are given by:

$$IRF_{j,t+h} = Y_{j,t+h}^* - Y_{j,t+h} \qquad \forall h \geq 0, \tag{10}$$

where $Y_{j,t+h}^* = \mathrm{E}\left[Y_{t+h} | s_t = j,\ \ Y_{t-1}, \varepsilon_{j,t}^*\right]$

$$= \sum_i P(s_{t+h} = i\ | s_t = j)(c_i + \emptyset_1 E\left[Y_{t+h-1} | s_t = j, Y_{t-1}, \varepsilon_{j,t}^*\right]$$

and $Y_{j,t+h} = \mathrm{E}\left[Y_{t+h} | s_t = j,\ \ X_{t-1}, \varepsilon_{2,t}\right]$

$$= \sum_i P(s_{t+h} = i\ | s_t = j)(c_i + \emptyset_1 E\left[Y_{t+h-1} | s_t = j, Y_{t-1}, \varepsilon_{j,t}\right]$$

V. DATA AND SPECIFICATIONS

In this section, we describe the data used to estimate the two models and the data transformations. We discuss the decision of how many lags to use in the VAR model. Concerning the MS-VAR model, we also specify the number of lags and regimes.

4.1 Data

The data consists of quarterly observations starting from the first quarter of 1985, and ending with the first quarter of 2017, for a total sample of 129 observations. All series are seasonally adjusted.

All series presented in this section are used to conduct this study with the VARs and MS-VARs model. The key variables are the Canadian Growth Domestic Product (*GDP*), the Economic Policy Uncertainty index in the United States (*U.S. EPU*), the Canadian Economic Policy Uncertainty index (*CANADA EPU*), the Canadian GDP (*GDP*), the Canadian Bank Rate (*BANK RATE*), and finally the Canadian Consumer Price Index (*CPI*).

The variables used are defined as follows:

U.S. EPU:	the log of the U.S. Economic Policy Uncertainty Index
CANADIAN EPU:	the log of the Canadian Economic Policy Uncertainty Index
GDP:	the log difference multiplied by 100 of the Canadian GDP
BANK RATE:	the annualized Canadian Bank rate
CPI :	the log annualized Canadian CPI excluding the 8 more volatile components identified by the Bank of Canada

Following Baker, Bloom and Davis (2016), we use the U.S. EPU index as a proxy variable to measure an uncertainty shock in the U.S. economy. We follow the same procedure for the Canadian EPU variable. This variable is constructed based on the news coverage of policy-related economic uncertainty, tax code expiration data, and economic forecaster disagreement. The Bank rate is used as a proxy to measure monetary policy. Table 1, found below, summarizes the statistics of all variables.

	Observations	Sample Mean	Standard Error	Skewness	Kurtosis	Maximum Value	Minimum Value
U.S. EPU	129	4.6532	0.2996	0.2306	-0.4216	3.9529	5.4599
Canada EPU	129	4.6748	0.4769	0.2558	-0.6179	5.8191	3.7655
GDP	128	0.5857	0.6698	-0.9964	2.7250	-2.3113	2.2895
Bank Rate	128	4.0415	0.7978	1.7239	13.9062	9.1080	1.2899
CPI	128	2.3275	1.6726	1.9990	9.4774	12.3725	-1.0918

Table 1: Descriptive statistics

We use the Augmented Dicky Fuller (ADF), and the Phillips and Perron (PP) to verify the stationary properties of the variables. These results can be found in Appendix A. ADF tests the null hypothesis of the unit root against the alternative of no unit root. PP tests the null hypothesis of no unit root against the alternative, the presence of a unit root. The two tests confirm that using the log of U.S. EPU and the first difference of the GDP presents no unit root.

4.2 Specifications

4.2.1 VAR Model

In order to determine the number of lags in the VARs, we start by estimating the models with one lag. Subsequently, we use the information criteria to choose the number of lags suitable for the models with a maximum of 5 lags.

The choice of the information criteria is made based on the extensive existing literature on model selection. The three criteria chosen seek to find a balance between good fit and parsimony. These penalized-likelihood criteria introduce a penalty term for the number of parameters in the model:

AIC: Akaike Information Criterion

BIC: Bayesian Information Criterion

HQ: Hannan-Quinn information Criterion

The penalty term is larger for the BIC and HQ criterion. We prioritize the BIC test to choose the number of lags. Appendix B presents the results of the different VARs used in this thesis. We find that, for this analysis, the most appropriate number of lags is 1 for all VARs.

4.2.2 MS-VAR Model

As mentioned in the previous section, the model chosen for the MS-VAR allows only the intercept to switch between regimes. Moreover, we use only two regimes in the model. This allows us to more accurately estimate the parameters with a stable model. We also can easily interpret the results in an economic way.

We use the information criteria AIC and BIC to choose the number of lags. Appendix B displays the results. As before, we prioritize the use of the BIC and use 1 lag to minimize the information criterion.

IV. EMPIRICAL RESULTS

As discussed, we seek to investigate the effect of a U.S. uncertainty shock on the Canadian economy with a VAR and MS-VAR model. First, we use a linear model to confirm previous work on the impact of U.S. uncertainty in Canada. Second, we show the asymmetry of behaviours during this shock using unconditional impulse responses in MS-VAR frameworks. We then replace the U.S. EPU variable with the Canadian EPU to study the difference between the impacts of the two shocks. These results provide insights into the importance of uncertainty in a small open economy such as Canada.

In section 5.1 we report the estimations of the VARs and their impulse responses. Section 5.2 presents the MS-VAR with regimes switching in intercept and unconditional impulse responses. Finally, we compare the findings in the two frameworks when replacing the U.S. uncertainty with the Canadian uncertainty.

5.1 Vector Autoregressive Analysis

In Appendix A, Figure 3 shows the responses of a U.S. uncertainty shock using the following VAR:

$$\boldsymbol{y} = [\boldsymbol{U.S.EPU}\,, \boldsymbol{GDP}\,]$$

As expected, a unitary increase of U.S. uncertainty decreases the Canadian GDP. Following the increase in uncertainty, there is an immediate decrease in GDP. The lowest point occurs in the second quarter with a change of -0.5. There is then a slow rebound, and the GDP reaches its initial level after 12 quarters. The confidence bands are drawn as an interval of 32%-68%. These results are statistically significant.

Table 9 reports the estimation of a VAR composed of U.S. uncertainty, Canadian GDP, the Canadian bank rate, and Canadian inflation:

$$\boldsymbol{y} = \left[\boldsymbol{U.S.EPU}\,, \boldsymbol{GDP}\,, \boldsymbol{BANK\ RATE}\,, \boldsymbol{CPI}\ \right]$$

In Figure 4, we observe that a unitary shock of the variable U.S. EPU significantly affects the Canadian GDP. The effect is similar to the results from the VAR with two variables. The bank rate is statistically significant after the second quarter. The variable decreases to reach its lowest point during the fourth quarter at -0.25, followed by a rebound to reach its initial states after 13 quarters. The bank rate decreases during high uncertainty and a decrease of GDP. Inversely, when the economy is in recession, the bank rate increases. The variable CPI is statistically significant on impact. After the second quarter, the CPI is not statistically significant.

To summarize, these estimations provide insight on how the economy will react to a unitary uncertainty shock. As expected, during high U.S. uncertainty, the Canadian GDP decreases significantly. The bank rate also decreases in response to this change. After confirming previous work, we can ask ourselves if a linear model characterizes sudden crisis in the Canadian economy.

Therefore, we need to push the empirical analysis of this thesis using a MS-VAR model to consider these differences in the different regimes. Using a conventional VAR to estimate the relationship between U.S. uncertainty and the GDP can lead us to underestimate the responses when the economy is in expansion and overestimate them when the economy is in recession. We use unconditional impulse responses of a U.S. uncertainty shock on the Canadian economy that allow for regime switches after the initial shock. The next section carries the primary purpose of this thesis in filling a gap in existing literature on this topic.

5.2 Markov-Switching Vector Autoregressive Analysis

We begin by estimating the MSI(2)-VAR(1) with regimes switching only in intercept with 2 regimes and 1 lag. Each regime is characterized by a different intercept μ in the two distinct regimes: recession and expansion. The matrix of autoregressive parameters $\emptyset$ and the variance-covariance matrix Σ_τ are common regarding the state of the economy. The state of the economy depends on the unobserved variable s_{t}.

We first report parameter estimates found using the maximum likelihood methodology. An examination of Table 8 reveals that the intercept μ of the Canadian GDP is quite different across the two regimes. During a recession, a high uncertainty is implied. We estimate the coefficient of the intercept 1.92 for recession and 1.77 for expansion. The GDP is differs greatly across the two regimes, indicating the asymmetry between recession and expansion. In the former, the intercept is 0.28, while in the expansion regime the coefficient is 1.74. This difference reflects the non-linearity depending on the state of the economy. These results are statistically significant.

The expected duration [4]is approximately 2.8 quarters for the recession regime. The expansion regime is very persistent with a period of 51.6 quarters. Therefore, the duration for the expansion period is 18 times that of the recession. Logically, this estimation indicates the expected growth of the Canadian GDP is much longer during an expansion than a recession.

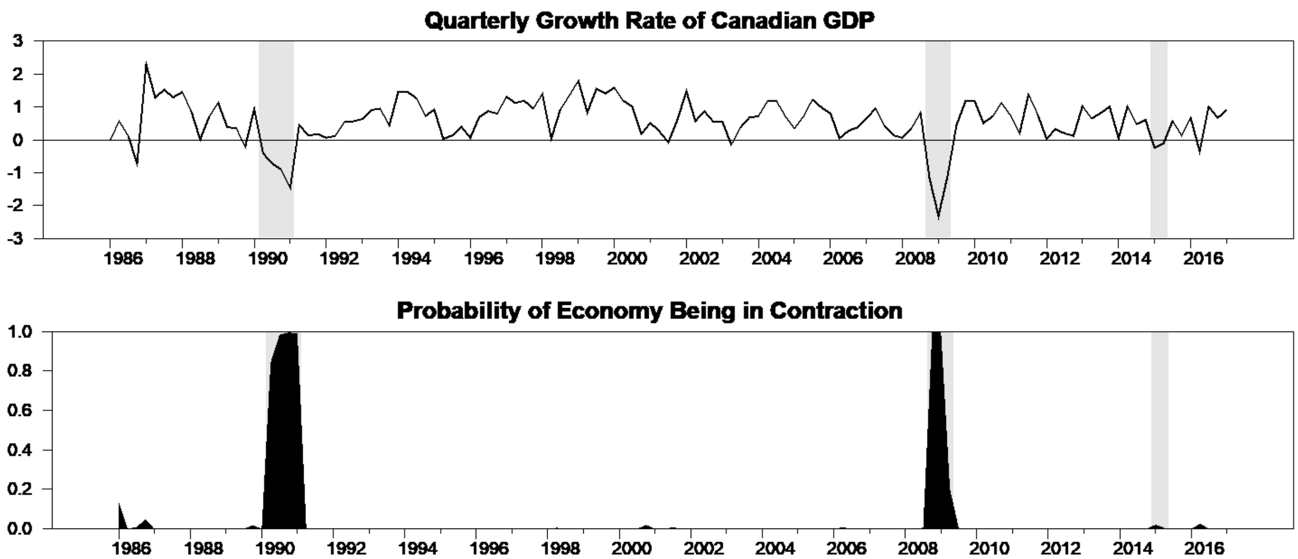

Figure 2: Smoothed probabilities for the MSI(2)-VAR(1) model.

The upper window of Figure 2 highlights the growth rate of the Canadian GDP in grey during the periods of recession between 1985Q1 and 2017Q1. We can observe a recession in 1990, 2008-09, and 2015. The lower part of the plot is the smoothing probabilities of the Canadian economy during recession. The probability of recession increases during the peak levels in 1990, and 2008-2009 as

[4] Expected duration in recession: (1/ (probability of staying in the recession regime)). Expected duration in expansion: (1/ (probability of staying in the expansion regime)).

expected. We can also notice that the probability of recession is nearly non-existent in 2015. The decrease in oil prices put Canada in a technical recession due to its important exploitation. The observation of the growth rate of the GDP indicates that this drop is not significant, explaining why the probability of recession for 2015 is nearly zero.

Figure 7 shows the impact of a unitary U.S. uncertainty shock to the Canadian GDP in the MS-VAR. We can observe the marginal effect given in deviation from the unconditional mean. Following the work of Ehrmann, M., Ellison, M. & Valla, N. (2003), we performed 5,000 bootstrap simulations to draw the confidence band. We create artificial histories for the endogenous variables through the creation of hidden regime s_t. We then estimate the artificial histories through the same MS-VAR and identification strategy. Next, we compute the unconditional impulse responses. The confidence bands are estimated using bootstrap simulations with a confidence level of 32%-68%, represented in the figure by the black line.

In both regimes, the impulse response shows a statistically significant effect by U.S. uncertainty on the Canadian GDP. A closer look reveals that the magnitude of this effect is different across regimes. In an expansion regime, the GDP increases by to 0.12 during the first quarter. Then, it declines rapidly during the second and third quarters to reach a bottom of -0.19. After the third quarter, the GDP rebounds and reaches its initial level after 10 quarters.

The effect on the Canadian GDP in a recession regime is quite different. The effect is much more pronounced. The GDP rapidly decreases by 1.34, then bottoming out after the second quarter at -1.56. Then the GDP rebounds to reach its initial level after 10 quarters.

To conclude, a unitary U.S. uncertainty shock has a deeper impact on the Canadian economy during a recession than during an expansion. We also find that the uncertainty shock has a more sudden effect at the initial impact.

Surprisingly, the recovery from a U.S. uncertainty shock is similar for both regimes. For both, the Canadian economy takes about 10 quarters to recover. We would expect the recovery to be shorter for an expansion regimes than a recession.

Moreover, comparing a traditional VAR with a MS-VAR can introduce some additional insights. As expected, the VAR lies in between the impulse responses of the recession regime and the expansion regime of the MS-VAR. It helps to understand the impact of the states of the economy when uncertainty suddenly rises. The MS-VAR gives us more information on the difference of the behaviour of a U.S. uncertainty shock in the Canadian economy depending on the state. This difference should be considered not just by policymakers, but also by enterprises and households.

5.3 VAR and MS-VAR Framework with Canadian Uncertainty

In this section, we replace the variable U.S. EPU with the Canadian EPU. As discussed previously, this variable is constructed with the same methodology. We therefore estimate the same models with the same methodology.

Figure 5 shows the traditional impulse responses with Canadian EPU and the Canadian GDP. We can observe a sudden drop in uncertainty with the first quarter of 0.31, reaching a low of 0.32 during the second quarter. A restoration to original levels then takes 15 quarters. This first result points to the fact that the negative effect of a U.S. shock in the Canadian economy is more sudden, but the magnitude is lower. Moreover, it also takes more time for the economy to recover.

In Figure 6, we include the bank rate and the CPI. We can note that the bank rate is still statistically significant after the second quarter. The variable decreases and hits its lowest point of -0.23 during the third quarter. As shown in the data, this magnitude is lower with a Canadian uncertainty shock than a U.S. uncertainty shock. The CPI drop is also statistically significant. The inflation reaches its bottom of -0.45 during the second quarter. The increase of Canadian uncertainty acts as an aggregate demand shock. In these results, we find that CPI is not statistically significant. The recovery from a Canadian uncertainty shock is also shown to take longer than after a U.S. shock.

Figure 8 shows the unconditional impulse responses of a Canadian uncertainty shock to the Canadian GDP. As expected, we can observe asymmetry in the responses between the two regimes. In expansions, the GDP decreases instantly and reaches a bottom of -0.15 after the second quarter. It then recovers to reach its initial level after 20 quarters. In recessions, the GDP decreases directly to its lowest point of -1.6, and rebounds more quickly than during the expansion state.

In expansion regimes, a Canadian uncertainty shock has a quicker but lesser impact on the economy than a U.S. shock. In the expansion regimes, the impact is similar in both unconditional impulse responses. The recovery from a Canadian uncertainty shock is longer for the expansion regimes. Concerning the recession regimes, the recovery is similar between the two shocks.

VI. CONCLUSIONS

The existing literature that studies the impact of uncertainty in the macroeconomic environment focuses on the U.S., the U.K., and the euro zone using linear and non-linear models. In Canada, some works focus on uncertainty using a linear model, while little work has been undertaken using a non-linear model. To the best of our knowledge, this is the only study to use unconditional impulse responses by way of a MS-VAR to capture the effect of uncertainty in the Canadian economy.

In this study, two approaches are used to identify the impact of U.S. uncertainty on the Canadian economy. The first approach is to use a multivariate VAR which finds that an increase in U.S. uncertainty decreases Canadian GDP. This confirms the results in past studies.

The second approach consists of using a MS-VAR with a regime switch in the intercept. We produce an unconditional impulse response to measure the effect of U.S. uncertainty. The empirical study shows that the responses are asymmetric between the regimes. The effect is deeper and quicker in the recession regime.

Finally, we provide insight to the difference between a U.S. and a Canadian uncertainty shock. With the latter, the effect is lower in the expansion regime and the recovery takes longer. In the recession regime, the responses are very similar between the two shocks.

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APPENDIX

A. Unit Root

Variables	In levels	1st difference
U.S. EPU	-5.08822**	-5.30701**
Canada GDP	0.35245	-6.74701**

Table 2: Augmented Dicky Fuller test

Lags	U.S. EPU (in levels)	U.S. EPU (1st difference)	GDP (in levels)	GDP (1st difference)
0	-5.34897**	-5.12844**	0.85870	-6.80077**
1	-5.27858**	-4.97797**	0.64784	-6.77821**
2	-5.13622**	-4.86815**	0.55653	-6.81600**
3	-5.18703**	-4.97875**	0.51304	-6.83245**
4	-5.31129**	-5.11049**	0.48585	-6.82486**
5	-5.42724**	-5.19729**	0.46468	-6.85592**
6	-5.56185**	-5.32500**	0.45033	-6.88034**

Table 3: Phillips and Perron test

B. Information Criterion

B1. Variable U.S. EPU

Lag	VAR (U.S. EPU, GDP)		
	BIC	AIC	HQ
1	**1.90***	1.76	**1.81***
2	2.03	1.81	1.89
3	2.09	1.78	1.90
4	2.14	**1.75***	1.90
5	2.29	1.82	1.99

Lag	VAR (U.S. EPU, GDP, Bank Rate, CPI)		
	BIC	AIC	HQ
1	**8.33***	**7.89***	**8.06***
2	8.89	8.11	8.40
3	9.29	8.20	8.58
4	9.74	8.36	8.81
5	10.19	8.55	9.04

Table 4: Selection of the number of lags with information criterion: AIC, BIC and HQ in VAR models

Lag	MS-VAR (U.S EPU, GDP)	
	BIC	AIC
1	**1.988*****	1.693
2	2.07	1.685
3	2.133	1.658
4	2.243	**1.674*****

Table 5: Selection of the number of lags with information criterion: AIC, BIC in MS-VAR models

B2. Variable CANADA EPU

Lag	VAR (CANADA EPU, GDP)		
	BIC	AIC	HQ
1	**2.40***	2.27	**2.32***
2	2.52	2.29	2.38
3	2.53	2.22	2.34
4	2.60	**2.21***	2.36
5	2.74	2.27	2.44

Lag	VAR (CANADA EPU, GDP, BANK RATE, INFLATION)		
	BIC	AIC	HQ
1	**8.78***	**8.33***	**8.50***
2	9.27	8.49	8.78
3	9.63	8.54	8.92
4	10.08	8.70	9.15
5	10.54	8.90	9.39

Table 6: Selection of the number of lags with information criterion: AIC, BIC and HQ in VAR models

Lag	MS-VAR (CANADA EPU, GDP)	
	BIC	AIC
1	**2.522*****	2.228
2	2.648	2.263
3	2.658	2.182
4	2.747	**2.179*****

Table 7: Selection of the number of lags with information criterion: AIC, BIC and in MS-VAR models

C. Estimation of VAR and MS-VAR

C1. Variable U.S. EPU

$Y_t = (U.S\ EPU, GDP)'$	**Coefficient**	**Std Error**
μ1	1.7430*	0.3400
μ2	2.1125*	0.8639
ϕ11	0.6305*	0.0818
ϕ12	-0.0351	0.0919
ϕ21	-0.3805*	0.0525
ϕ22	0.4178*	0.1811
σ11	0.0529*	0.0806
σ12	-0.0073	0.0423
σ21	-0.0073	0.0752
σ22	0.3408*	0.0926

Table 8: Estimation of the VAR: (*U.S. EPU, GDP)*

$Y_t = (U.S\ EPU, GDP, BANK\ RATE\ INFLATION)'$		Std Errors	
μ	$\begin{pmatrix} 1.6472* & 1.8249* & 3.0192* & 0.6036 \end{pmatrix}$	μ	$\begin{pmatrix} 0.3422 & 0.7553 & 0.0672 & 0.0511 \end{pmatrix}$
$\emptyset_t$	$\begin{pmatrix} 0.6227* & -0.0563 & 0.0411 & -0.0095 \\ -0.3598* & 0.4133* & 0.0426 & 0.0098 \\ -0.0448 & 0.4519* & 0.2247* & 0.0264 \\ 0.2224 & 0.0406 & -0.0586 & 0.3851* \end{pmatrix}$	$\emptyset_t$	$\begin{pmatrix} 0.0423 & 0.1134 & 0.0332 & 0.0255 \\ 0.0576 & 0.0478 & 0.0546 & 0.0288 \\ 0.0441 & 0.0159 & 0.0532 & 0.0311 \\ 0.0384 & 0.0406 & 0.0274 & 0.0127 \end{pmatrix}$
Σ_t	$\begin{pmatrix} 0.05286 & -0.00750* & -0.04713 & 0.01236* \\ -0.00750* & 0.34066 & -0.05731* & 0.05368 \\ -0.04713 & -0.05731* & 0.14743 & 0.09333 \\ 0.01236* & 0.05368 & 0.09333 & 0.03186 \end{pmatrix}$	Σ_t	$\begin{pmatrix} 0.0161 & 0.0067 & 0.0183 & 0.0281 \\ 0.0067 & 0.0304 & 0.0289 & 0.0147 \\ 0.0183 & 0.0289 & 0.0103 & 0.0073 \\ 0.0281 & 0.0147 & 0.0073 & 0.0078 \end{pmatrix}$

Table 9: Estimation of the VAR: (U.S. EPU; GDP; Bank Rate; CPI)

$Y_t = (U.S\ EPU, GDP)'$	**Recession**	**Std Error**	**Expansion**	**Std Error**
μ1	1.922*	0.3554	1.7710*	0.3332
μ2	0.285*	0.7295	1.7493*	0.6681
ϕ11	0.6211*	0.0706	0.6211*	0.0706
ϕ12	-0.0199	0.1416	-0.0199	0.1416
ϕ21	-0.2725	0.0308	-0.2725	0.0308
ϕ22	0.2854*	0.2900	0.2854*	0.2900
σ11	0.0526*	0.0056	0.0526*	0.0056
σ12	0.0024	0.012	0.0024	0.012
σ21	0.0024	0.012	0.0024	0.012
σ22	0.2438*	0.0296	0.2438*	0.0296
Expected duration (quarters)	2.79		51.55	

Table 10: Estimation of the MSI(2)-VAR(1): (*U.S. EPU, GDP)*

C2. Variable CANADA EPU

$Y_t = (Canada\ EPU, GDP)'$	Coefficient	Std Error
μ1	0.9749*	0.2874
μ2	1.2677*	0.5669
ϕ11	0.7931*	0.0595
ϕ12	0.0044	0.0418
ϕ21	-0.1982	0.1174
ϕ22	0.4186*	0.0826
σ11	0.0883*	0.0344
σ12	-0.0282	0.0556
σ21	-0.0282	0.054
σ22	0.3449*	0.0993

Table 11: Estimation of the VAR: (*CANADA EPU, GDP)*

$Y_t = (CANADA\ EPUU, GDP, INFLATION, BANK\ RATE)'$		Std Errors	
μ	$(0.11989* \quad 1.81161* \quad -0.10818* \quad 3.35965*)$	μ	$(0.3922 \quad 0.4553 \quad 0.0433 \quad 0.0459)$
$\emptyset_t$	$\begin{pmatrix} 0.91652* & 0.04943 & -0.00043* & 0.06227 \\ -0.33456* & 0.47688* & -0.02261 & 0.02313 \\ -0.15395 & 0.25443 & 0.37715* & 0.15879* \\ -0.05484 & 0.39909 & 0.04194* & 0.17858 \end{pmatrix}$	$\emptyset_t$	$\begin{pmatrix} 0.1173 & 0.1510 & 0.0034 & 0.0281 \\ 0.0109 & 0.0861 & 0.0310 & 0.0428 \\ 0.0307 & 0.0201 & 0.0376 & 0.0193 \\ 0.0320 & 0.0331 & 0.0067 & 0.0045 \end{pmatrix}$
Σ_t	$\begin{pmatrix} 0.08818 & -0.02842* & -0.07653 & 0.02291 \\ -0.02842* & 0.2970 & -0.08288 & 0.06210* \\ -0.07653 & -0.08288 & 0.02334 & 0.07601 \\ 0.02291 & 0.06210* & 0.07601 & 0.03772 \end{pmatrix}$	Σ_t	$\begin{pmatrix} 0.0283 & 0.0077 & 0.0119 & 0.0081 \\ 0.0077 & 0.0140 & 0.0132 & 0.0107 \\ 0.0119 & 0.0132 & 0.0090 & 0.0098 \\ 0.0081 & 0.0107 & 0.0098 & 0.0190 \end{pmatrix}$

Table 12: Estimation of the VAR: (CANADA EPU, GDP, Bank Rate, CPI)

$Y_t = (Canada\ EPU, GDP)'$	**Recession**	**Std Error**	**Expansion**	**Std Error**
μ1	1.1476*	0.7355	0.9528*	0.6089
μ2	-0.2764	2.4343	1.2132*	2.3703
ϕ11	0.7924*	0.1033	0.7924*	0.1033
ϕ12	-0.1511*	0.5479	-0.1511*	0.5479
ϕ21	0.0302	0.1724	0.0302	0.1724
ϕ22	0.2574*	0.0504	0.2574*	0.0504
σ11	0.0876*	0.0114	0.0876*	0.0114
σ12	-0.0157	0.0176	-0.0157	0.0176
σ21	-0.0157	0.0176	-0.0157	0.0176
σ22	0.2417*	0.0306	0.2417*	0.0306
Expected duration (quarters)	2.95		51.28	

Table 13: Estimation of the MSI(2)-VAR(1): (*CANADA EPU, GDP)*

D. Impulse Responses

D1. Variable U.S. EPU

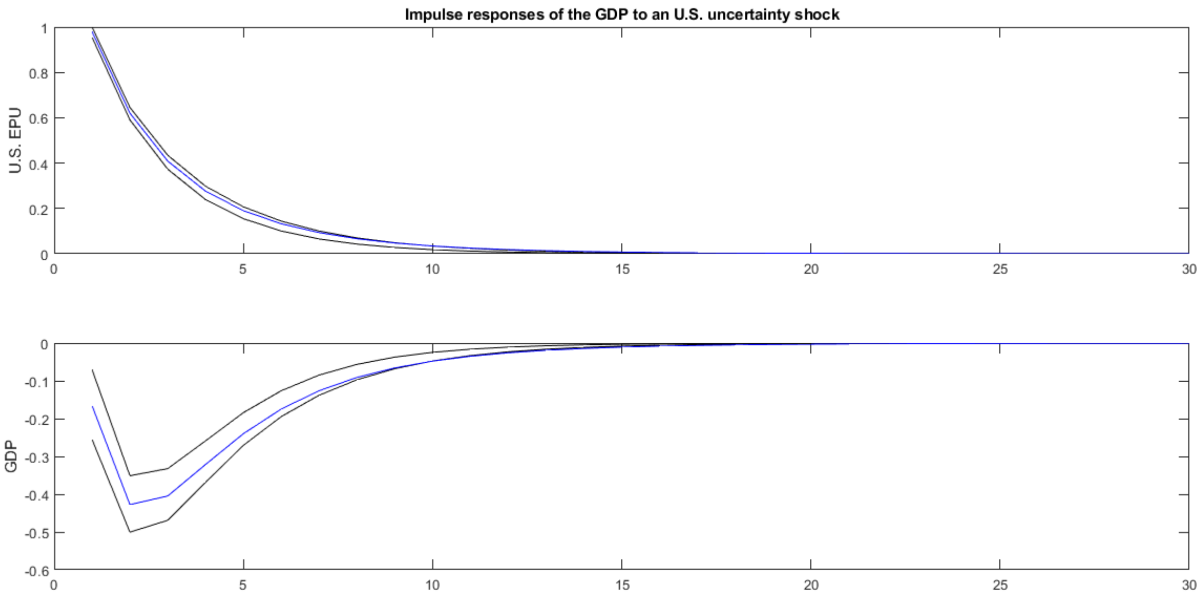

Figure 3: Impulse responses to a unitary U.S. uncertainty shock in the VAR (*U.S. EPU, GDP*)

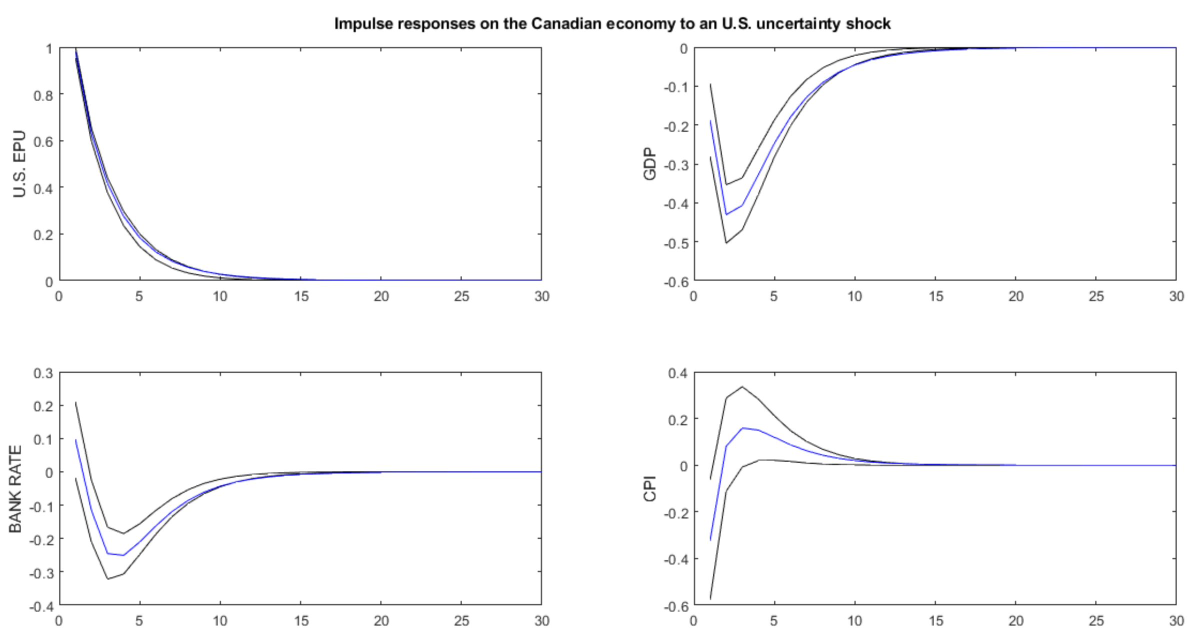

Figure 4: Impulse responses to a unitary U.S. uncertainty shock in the VAR (*U.S. EPU, GDP, Bank Rate, CPI*)

D2. Variable CANADA EPU

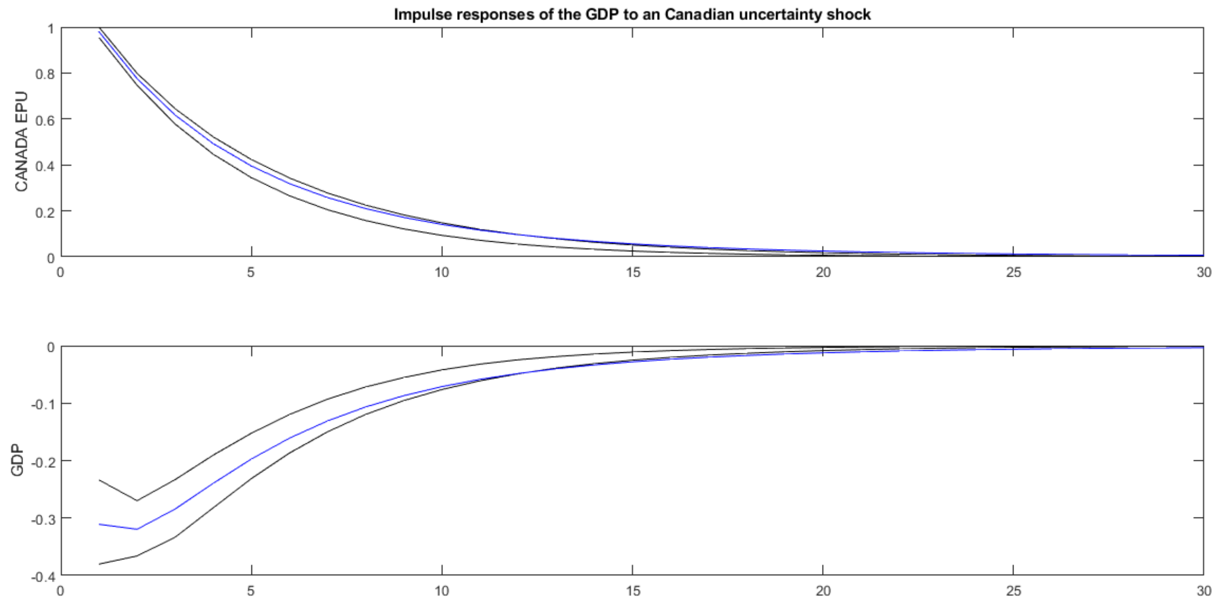

Figure 5: Impulse responses to a unitary Canadian uncertainty shock in the VAR (*CANADA EPU, GDP*)

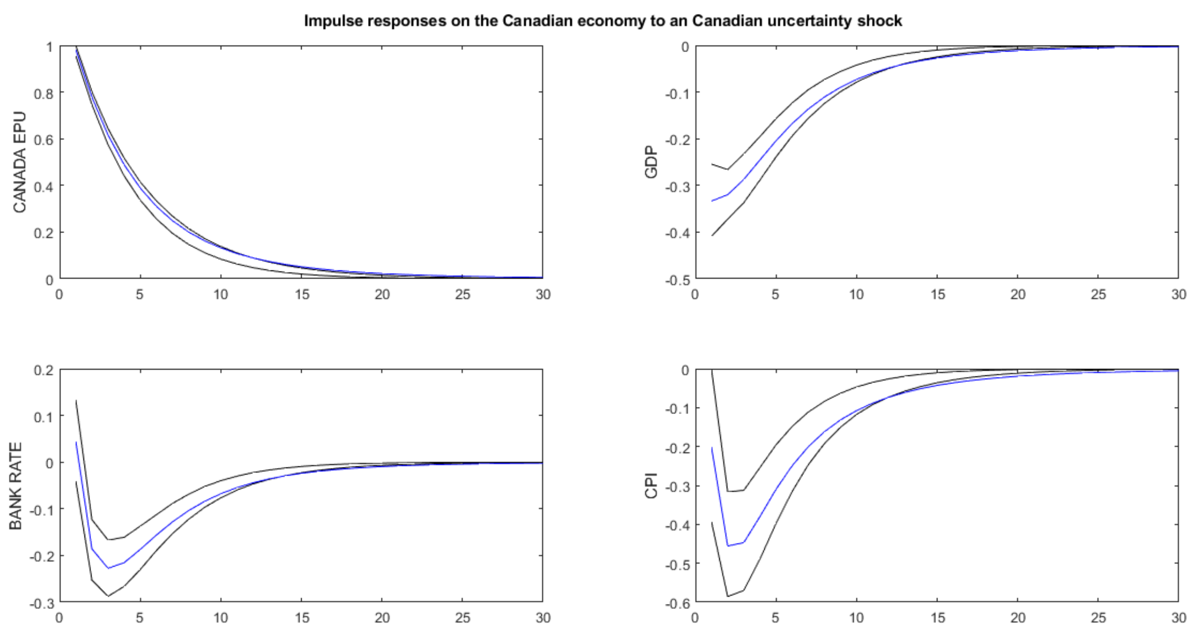

Figure 6: Impulse responses to a unitary Canadian uncertainty shock in the VAR (*CANADA EPU, GDP, BANK RATE, CPI*)

E. Unconditional Impulse Responses

E1. Variable U.S. EPU

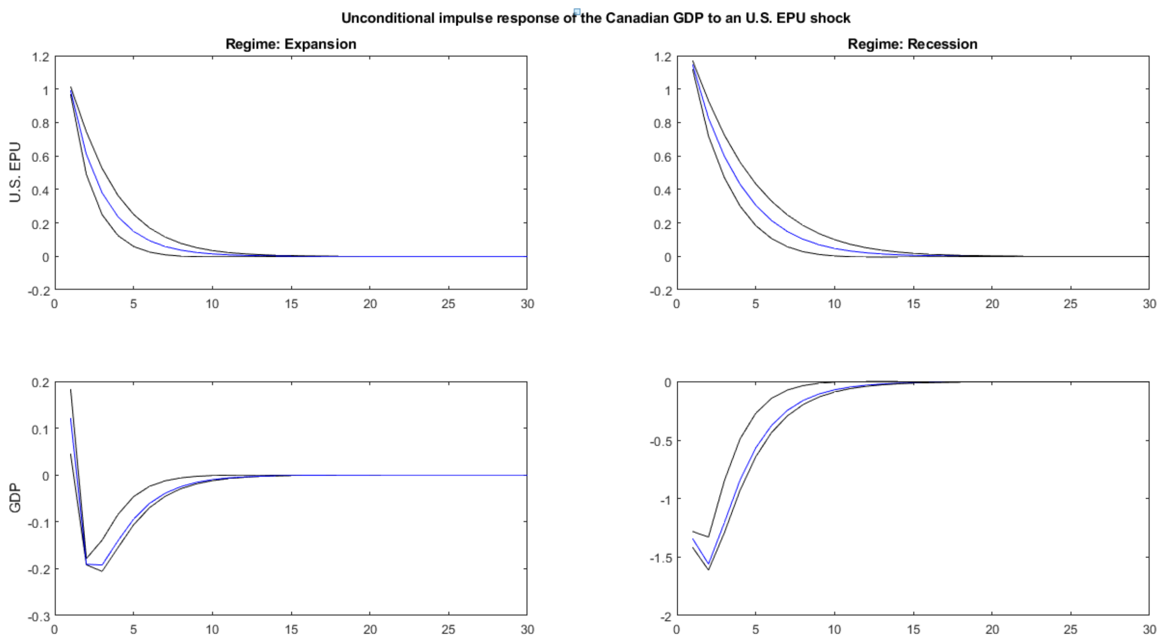

Figure 8: Unconditional Impulse Responses of the MSI(2)-VAR(1): (*U.S. EPU, GDP)* to a unitary U.S. uncertainty shock. Point estimate impulse responses to a unitary U.S. uncertainty shock on the Canadian economy. Marginal effect given in deviation from the unconditional mean. Black line: 32% - 68% confidence band.

E2. Variable CANADA. EPU

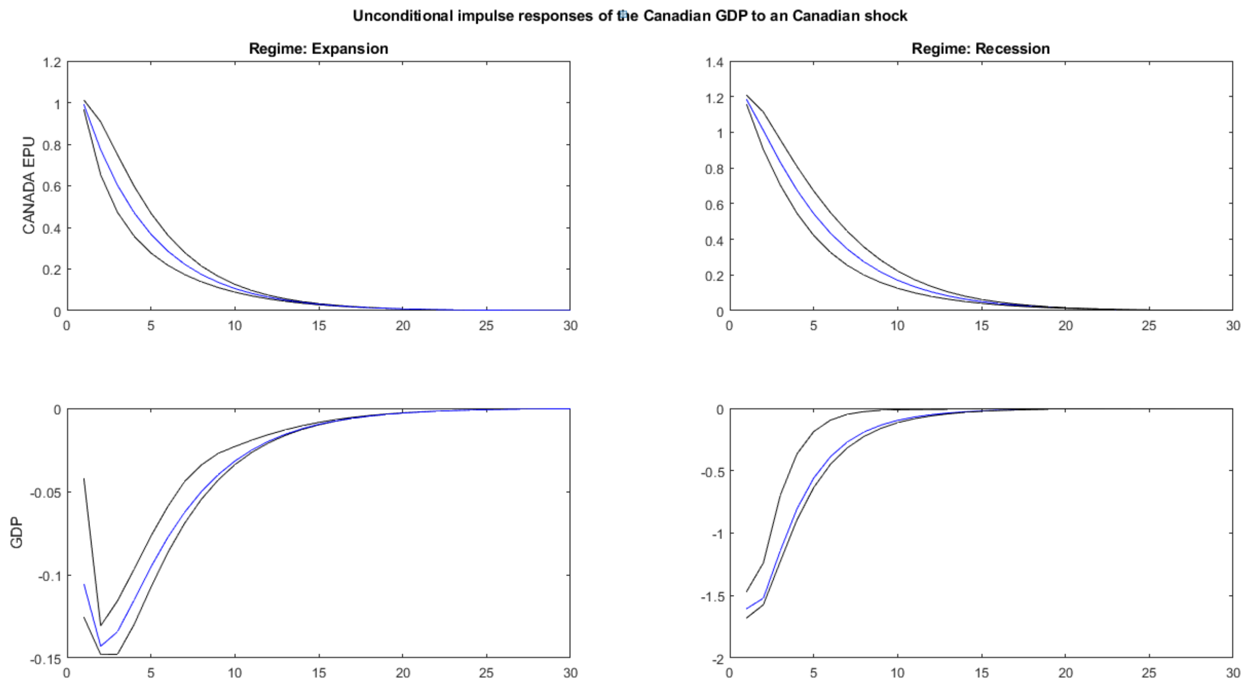

Figure 10: Unconditional Impulse Responses of the MSI(2)-VAR(1): (CANADA EPU, GDP) to a unitary Canadian uncertainty shock. Point estimate impulse responses to a unitary Canadian uncertainty shock on the Canadian economy. Marginal effect given in deviation from the unconditional mean. Black line: 32% - 68% confidence band.