The Impact of Climatic Shocks on Alberta's Economy: A Vector Autoregression Analysis

by

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Abstract

Climate change is posing a major challenge to our environment and economy. Climate change is considered to be more intense for northern regions including Alberta, Canada. Adapting to climate change is essential to mitigate the negative impacts and maintain prosperity for society. However, the lack of regional knowledge of economic impacts of climate change may stall or slow the adaptation. Using a novel approach—the VARX (vector autoregression with exogenous variables) model—this study traces out the quarterly response of economic growth (i.e., total GDP growth, agricultural GDP growth and non-agricultural GDP growth) to two climatic shocks: temperature and precipitation shocks (based on quarter-to-quarter fluctuations in temperature and precipitation) in Alberta, Canada over the period from 1986 to 2007. Our specification of VARX model is based on the theoretical and empirical economic growth literature, thereby, allowing us to isolate climate change effects from other growth determinants. We pay particular attention to controlling for the effect of oil price changes since Alberta is an energy-based province with the largest share of GDP due to the energy sector. The VARX model is able to capture the simultaneous effects of climate change on different economic sectors. We use population-weighted climate variables to account for the different distributions of economic activities and climate variables.

The results indicate that temperature shocks tend to induce significant and negative impacts on the three types of GDP growth; precipitation shocks tend to result in overall positive (but not significant) impacts on economic growth. The agricultural sector is more sensitive to climatic shocks. Considering both climatic shocks together, we conclude it is

more likely that expected future climate change would result in a net negative impact on economic growth, particularly in the agricultural sector, for Alberta. Moreover, the results of a novel in-sample simulation exercise conducted using the VARX model estimates suggest that a 30% increase in temperatures leads to an average reduction of 2% on quarterly agricultural GDP growth during growing season. Precipitation increases may partially alleviate negative impacts from extreme high temperatures especially for agricultural production.

The results shed light on significant linkages between climate change and its economic impacts as they permeate through output and input markets (viz., and captured in our GDP growth specification). However, climate change could also affect non-market activities such as human health and ecosystem services. It is, therefore, important for future research to investigate the social welfare impacts of climate change that include these non-market effects.

Dedication

To my dear parents and grandparents

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1. Introduction

1.1 Climate Change and the Economy

Climate change is a combination of natural climate variability and the effects of human activities on the environment. Scientific evidence suggests that the global temperature will increase from 0.3 to 0.7°C for the period between 2016 and 2035 relative to 1986 to 2005. (IPCC 2014). The rate of increase in temperature is faster than what has ever been observed historically. Human activities produce greenhouse gas emissions causing increased concentration of carbon dioxide (CO_2) in the atmosphere, which is considered the main factor behind global warming[1] over the past 50 years (NASA 2015). Climate change is causing a host of changes such as a rise in global sea levels, increase in acidity of surface ocean waters, decline in arctic ice sheets and retreating glaciers (Church and White 2006; Kaser et al. 2006; Kwok and Rothrock 2009; NASA 2015; NOAA 2015; UNEP 2015). Climate change could also change the intensity, spatial extent, duration and/or timing of extreme weather events (e.g., floods, droughts, heat waves and storms) (IPCC 2012). Moreover, warming tends to increase the probabilities of these extreme weather events.

Climate change will induce different impacts across different regions and countries. This is because, overall, the northern regions have been undergoing more rapid warming than other parts of the world (IPCC 2013). Countries with different levels of development, economic structures, and climate policies will be affected differently by climate change. The impacts of climate change will also differ across different economic sectors. The economic impact of climate change is important to understand due to its long time scale, nature of uncertainties, international scope and uneven distribution of corresponding benefits and costs across space and time.

The agricultural sector is considered the most vulnerable and sensitive sector to climate change. This is because climatic conditions such as temperature and precipitation are direct

[1] Climate change is defined as a significant variation from average weather conditions such as temperature, precipitation and wind pattern in the long term (IPCC 2007). Global warming is to describe the observed rise in the average temperature of the earth's climate system.

inputs to agricultural production. Due to its vulnerability and sensitivity, the agricultural sector has drawn a great deal of attention from scholars. Researchers have utilized various approaches (e.g., biophysical crop models, production functions, profit functions, and hedonic approaches) to analyze the impacts of climate change on agriculture. The impacts of climate change on agriculture will be passed on to other sectors indirectly and other sectors also are affected by climate change directly at the same time. Looking at the agricultural sector in isolation misses general equilibrium effects that emerge from the interactions among diverse sectors and may mask a truly response to climate change for each sector.

Recent work has also conducted economy-wide analysis by using modelling approaches (e.g., computable general equilibrium (CGE) models and integrated assessment models (IAM)) to investigate such impacts on agricultural output and total output. However, these approaches tend to be based on strict neoclassical assumptions or make strong assumptions on the interactions between economic variables and climate variables, which may lack adequate economic and scientific knowledge to support them (e.g., Pindyck 2015). In addition, the different approaches tend to differ in the structure, equations, parameters, and data used in the model. Some previous research is policy focused in nature and produces findings that support specific policy recommendations (Nordhaus 2008). Because of these issues, no consensus on the economic impact of climate change has been reached.

Climate change is deemed to be one of the most challenging threats facing society. The impacts of climate change permeate economic activities, human health, and ecosystems. The challenge of coping with climate change is difficult because it spans various disciplines, many parts of society, and different jurisdictions. Inaction to climate change could be catastrophic. It is estimated that if no mitigating actions are taken, the overall cost of climate change will be at least 5% of global GDP each year, as reported by Stern (2006), and the present value of climatic change damage may be $22.6 trillion (in 2005 U.S. dollars), as found by Nordhaus (2008). Adapting to climate change is important to mitigate its negative impacts and lowering costs. With limits to our current knowledge, there is no clear answer on how much effort countries (regions) should take to slow down climate change, and how the reductions of CO_2 should be distributed among industries and regions. Information on the economic impacts of climate change is a necessary component of the information required to make such decisions.

The need for new information on the economic effects of climate change is particularly important for Canada. Most Canadian studies are dated and only a few of them are economy-wide and have analyzed the impacts of climate change at the regional level (Ochuodho and Lantz 2015). Regional studies are required to reveal the hidden details in the aggregation and therefore to produce more targeted policies. More specifically, no studies have examined the effect of climate change on Alberta's economic growth despite the immense relevance of this issue for Alberta's economy.

1.2 Overall Goal and Research Objectives

Using the VARX (i.e., vector autocorrelation regression with exogenous variables) model, this study aims to shed light on the impacts of climate change on GDP growth in a Canadian province—Alberta. GDP is an important indicator to measure the health of a region's economy. Understanding GDP growth conditioned on climate change is of paramount importance to the nation and the province. It raises the awareness of the potential threats by climate change. It disseminates knowledge to stakeholders interested in climate change policy. It provides information for decision makers to design and evaluate climate policies and instruments that are aiming to adapt to, or mitigate factors leading to, climate change. It provides information to complex mathematical modelling approach to produce more accurate implications. The lack of empirical work on this issue is especially striking since economists have been modelling the determinants of economic growth in Canada for decades. The number of studies on this issue (reviewed in an upcoming section) is considerable. However, none of the studies that we are aware of include climate change as an explanatory variable in their economic growth models[2]. If climate change has a significant effect on GDP growth, as

[2] Recent studies (e.g., Dell et al. 2013 and Moyer et al. 2014) have demonstrated the climate impacts on economic growth.

hypothesized in this thesis, then the Canadian economic growth literature, taken as a whole, has ignored a potential source of omitted variable bias in their estimates.

The overall goal of this study is to investigate how climatic shocks affect economic growth in Alberta. The climatic shocks considered in this study include temperature and precipitation shocks. Specific objectives of the study include:

1) To analyze the quarterly response of Alberta's agricultural, non-agricultural, and total GDP growth to temperature and precipitation shocks.

2) To evaluate the application of population-weighted climate variables to account for the different distribution of climate variables and economic activities.

3) To simulate the economic impacts under different climate change scenarios, particularly the impacts of the temperature-precipitation interactions on GDP growth.

1.3 Contribution to the Literature

At a provincial level, a VARX model based on population-weighted climate variables is used to account for the different distribution of climate and economic activities across the province. Using a time series model rather than an econometric model identified by economic assumptions, the VARX model is based on statistical regularities instead of uncertain assumptions. Given our limited knowledge of the structure of economy-climate relationships, the VARX model is flexible and more suited to examining the economic impacts of climate change. A novel VARX approach would provide different perspectives and insights that cannot be obtained from the other methods discussed above.[3] This study is, to the best of our knowledge, the first to provide knowledge on economic impacts of climate change in terms of GDP growth in a Canadian context by using the VARX model. This knowledge is essential for Alberta (Canada) to better understand the potential threats posed by climate change. Decision makers can also utilize the knowledge for policy designed to adapt to climate

[3] Traditional IAMs assume climate change only affects the level of GDP not its growth rate. The distinction between the level effects and the growth effects is that the former is transitory, while the latter is persistent and carried into the future (Moore and Diaz 2015). The VARX results may be helpful in modifying the assumptions in the IAMs.

change.

1.4 Outline of the Study

This study is organized in six chapters. Chapter 2 provides an overview of the relevant literature on climate change and its potential economic impacts, describes the study area—Alberta in terms of economy and climatic conditions, outlines the strengths and limitations of common approaches in previous literature and describes a promising approach—the VARX (i.e., vector autocorrelation regression with exogenous variables) model to investigate economic effects of climate change. The third chapter presents the data and methods. Chapter 4 provides the findings of this study. Chapter 5 provides a summary and the main conclusions. The last chapter highlights the limitations and possible extensions to this study.

2. Literature Review

2.1 Climate Change and Its Potential Economic Effects

2.1.1 Climate Change

Climate change is defined as a significant variation from average weather conditions such as temperature, precipitation and wind pattern for a long-term period of time (IPCC 2007). Global warming is a key effect of climate change. Scientific studies indicate that accumulated greenhouse gases including water vapour, carbon dioxide, methane and nitrous oxide are important driving factors of global warming (IPCC 2007). The increased level of heat-trapping greenhouse gases blocks the transfer of infrared energy through the atmosphere (NASA 2015). It is widely acknowledged that greenhouse gas emissions induced by human activities are the main cause of the global warming observed for the past 50 years (NASA 2015).

Climate Change 2014, the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC 2014), estimates that the global temperature will increase from 0.3 to 0.7°C for the period between 2016 and 2035 relative to 1986 to 2005. Over the last century, the burning of coal and oil driven largely by economic expansion and population growth has dramatically increased the concentration of atmospheric carbon dioxide (CO_2) (IPCC 2014). The pattern of climate change is not uniform across the globe. The northern regions on earth have experienced more rapid warming compared to their counterparts (IPCC 2013). In terms of precipitation, annual mean precipitation is likely to increase in the high latitudes, equatorial Pacific and the mid-latitude wet regions; while many mid-latitude and subtropical dry areas are likely to experience decreased annual mean precipitation (IPCC 2014).

Climate change could alter the frequency, intensity, spatial extent, duration and/or timing of many climate-related extreme weather events (e.g., floods, droughts, heat waves and storms) (IPCC 2012). Global warming will shift the distribution of temperatures and there will be more extreme hot days and fewer extreme cold days (IPCC 2014). Warmer days tend to increase the likelihood of the occurrences of these extreme weather events.

There is also other evidence that climate change is occurring. The global sea level rose about 17 cm in the past century (Church and White 2006). The rate of sea level rise in the last decade was almost double compared to that of the last century (Church and White 2006). Human activities induce more carbon dioxide emitted into the atmosphere and hence more CO_2 is absorbed by seawater. As the result, the acidity of surface ocean waters has increased by about 30 percent since the starting of the Industrial Revolution (NOAA 2015). Climate change also poses threats to potential water availability. The Greenland and Antarctic ice sheets have declined significantly, with losses of 150 to 250 cubic kilometers of ice per year from 2002 to 2006 for Greenland and 152 cubic kilometers between 2002 and 2005 for Antarctic (NASA 2015). Arctic sea ice has also declined rapidly over the past few decades (NASA 2015). The peak winter thickness in the Arctic Ocean had declined, with a value of 3.64 m in 1980 to that of 1.89 m in 2008. This reduction represents a 48% decrease in thickness (Rothrock and Kwok 2009). Retreating glaciers around the world (in the Alps, Himalayas, Andes, Rockies, Alaska and Africa) also provide clear evidence of climate change. Overall, the cumulative average ice loss over the past six decades exceeds 20 meters of water equivalent[4] (UNEP 2015). The annual contribution of glaciers and ice caps to sea level rise is estimated to be at one-third of a millimetre between 1961 and 1990; the rate is doubled for the period from 1991 to 2004 (Kaser et al. 2006) and increased to one millimetre per year for the period from 2000 to 2006 (UNEP 2015).

Evidence of climate change is also seen in Canada. The annual mean surface air temperature had increased by 1.5°C over the period between 1950 and 2010 (Vincent et al. 2012). Based on historical data, Vincent et al. (2015) find that warming is more significant in western Canada and total precipitation has increased mainly in the north. It is reported that Canada's High Arctic ice cap started to shrink in the late 1980s but the loss has accelerated rapidly since 2005 (Statistics Canada 2013). Recent work by Clarke et al. (2015) reports that

[4] The meter water equivalent (m.w.e.) is a common measurement of mass balance of glaciers. It is the amount of water contained within the snowpack. For example, the density of water is 1 g/cm^3, 1 m of water gives an interaction depth of 1 hectogram per square centimeter (hg/cm^2).

glacier ice in western Canada will shrink by 60% to 80% relative to the level in 2005, which will induce significant impacts on ecosystems and water availability. For extreme events, Wang et al. (2015) use the 95th percentile of Fire Weather Index (FWI_{95}) and the number of spread days to study the frequency of extreme fire weather events in Canadian forests. They report that the frequency will increase under the impact of climate change.

Climate change has created challenges for Canadian climate policies (Government of Canada 2015). The Intergovernmental Panel on Climate Change (IPCC) has urged a broad range of mitigation measures, such as climate policies, performance regulations and standards, voluntary agreements, information instruments, promotion of programs and financial incentives to control and reduce Greenhouse gases emissions (Kato et al. 2013). This would lead to a tendency for the Canadian economy to change to a low-carbon-intensive economic structure, thus affecting relevant economic outcomes (e.g., GDP and unemployment rate) (Government of Canada 2015).

2.1.2 Potential Economic Effects of Climate Change

Climate change is not only an environmental issue but also a global challenge for the economy. Economic growth and climate change are increasingly seen as being inextricably linked (see for example Uzawa 2003; Stern 2007; Greiner and Semmler 2008; Nordhaus 2008; Weitzmann 2009). It is estimated that if no specific actions are taken, the overall cost due to climate change will be at least 5% of global GDP each year (Stern 2006).

The economic impacts of climate change are not homogenous across sectors and regions. Agricultural productivity is affected by several climate factors, such as precipitation and temperature (Kaiser 1993), which makes agriculture one of the sectors most sensitive and vulnerable to climate change. Variations in temperature and precipitation would have significant impacts on crop and livestock production. Climate change is posing greater threats to developing counties than to developed countries. Firstly, most developing countries are located in warmer geographic regions. Secondly, developing countries, particularly the poorest, are heavily dependent on their agricultural sectors. The impacts due to climate change are therefore considered to be worse and more persistent for developing countries (Kousky 2012).

In contrast, climate change may initially have small positive effects on some economic activities in developed countries in higher latitudes. Small increases in temperature may lead to benefits through higher agricultural yields, lower winter mortality, lower energy requirements for heating and a possible boost to tourism (Stern 2006). However, extreme weather tends to happen more frequently with warming, which in turn may offset some of the benefits from climate change.

Clearly, given the vulnerability of the agricultural sector to climate change, understanding the potential impacts on the sector is important for world food supply and security. There is growing policy concern around the potential economic impact of climate change on agriculture (Fisher et al. 2012; IPCC 2014). Further, given the heterogeneous effects of climate change across regions and economic sectors, it is important to assess such impacts regionally and also to disaggregate total GDP impacts into agricultural and non-agricultural components (Fomby, Ikeda and Loayza 2013).

Climate change has both direct (e.g., on crop yield) and indirect impacts (e.g., spill-over effects through international markets) on the economy. The difficulty in differentiating these two types of impacts has led the existing literature to focus primarily on the direct impacts of climate change. Different approaches have been used to quantify the direct impacts of climate change on the agricultural sector. Early works utilized biophysical crop models estimating the impact of variations in temperature and precipitation on plant growth (e.g., Adams et al. 1990; Kaufmann and Snell 1997). These models only capture limited adaptation from producers to climate change, which may lead to overestimation of negative impacts (Deschenes and Kolstad 2011). Other studies have used production or profit functions to estimate the impacts of climate change. Production functions are estimated for specific crops as a function of climatic variables. For example, Schlenker and Roberts (2009) analyze the potential impacts of climate change on crop yields (for corn, soybeans and cotton) in the US. Crop yield is estimated as a function of temperatures and precipitation as well as other control variables. The authors argue that similar average temperatures may result from different temperature variations. Using averaged temperatures may mask the true response of crop yields to temperatures, because more exposure to extreme temperatures coming from wide temperature variations could have significant influence on crop yields. Instead, they use the total time length that each crop is exposed to each one-degree Celsius temperature over the growing season (e.g., the total hours that a crop is exposed to 21°C during the growing season). The results indicate that there is a non-linear relationship between crop yields and temperatures, and crop yields increase until a maximum temperature threshold is reached. Holding current land use fixed, they find that average yields for the major US crops would decrease by 30% to 46% before the end of this century even under the slowest warming scenario.

Major shortcomings of the production function approach are that it does not capture adaptations to climate change (e.g., farmers may change their mix of crops or use of fertilizers according to a change in climate) (Deschenes and Greenstone 2007). In addition, the variables are usually jointly determined and the potential of omitted variable bias occurs in the econometric model.

A profit function formulation may help address some of the potential problems in the production function approach. The profit function approach measures the economic impacts of climate change for a specific crop as a function of input and output prices, together with variation in weather. For instance, Deschênes and Greenstone (2012) estimate the effect of random year-to-year variation in temperature and precipitation on agricultural profits to study the economic effect of climate change. This model imposes a short run assumption of non-substitutability between crops. Using long-run climate change projections, the authors report warming will introduce a net loss to annual agricultural sector profits. Fisher et al. (2012) argue that with access to storage farmers are able to smooth weather-related shocks in time (i.e., based on the market price, farmers storage more and sell less in good years with postitive weather conditions while storage less and sell more in bad years with negative weather conditions). But the role of storage may not be captured by the profit function approach.

The Hedonic (or Ricardian) approach, introduced by Mendelsohn et al. (1994), attempts to link the value of the land and the characteristics of the land. The hedonic model is based on the notion that the prices of land reflect the net present value of all the expected future profits Ricardo (1817). Farmers maximize profits by allocating land to different economic activities and adjusting inputs and outputs. Therefore, the Hedonic approach is able to capture adaptation in contrast to production or profit functions. For example, Mendelsohn and Reinsborough (2007) study the response of agriculture to climate change between Canada and the United States. They apply a standard Hedonic method with a quadratic formulation of two climatic variables (seasonal temperatures and seasonal precipitation). The results suggest that the Canadian agricultural sector will not be stressed by warming and would benefit from more precipitation. In contrast, US farms are more sensitive to temperature rise and gain less from increased precipitation. The authors noted the difference between the two countries comes from the fact that Canada is colder and drier relative to the US. A key concern noted by Deschênes and Greenstone (2007) is that the hedonic approach may confound climate with other unmeasured land characteristics, which lead to unknown bias in the sign and magnitude of the resulting omitted variables.

Agriculture is the sector that has been most extensively studied to explore the economic impacts of climate change (Fisher et al. 2012). However, due to its complexity, consensus on the potential economic impacts of climate change on agriculture is still far from being achieved (Deschênes and Greenstone 2012; Fisher et al. 2012). Zhai et al. (2009) and Ochuodho and Lantz (2015) find that the impacts of climate change on agriculture may not have a similar direction with that on other economic activities (e.g., total GDP). IPCC (2007) notes climate change will affect various sectors simultaneously. Climate change would affect other sectors either through direct or indirect effects. A growing body of research has turned to explore the overall economic impacts of climate change for the economy as a whole.

Understanding the overall economic impact requires an integration of data and models and knowledge about the relationship between climate change and the economic outcomes.

Several modelling approaches have been used to pursue this avenue of research. For example, a computable general equilibrium (CGE) model consists of equations describing model variables and a corresponding database to characterize the interactions between different economic activities. A CGE model may be effective to assess two future outcomes with and without climatic shocks.

Ochuodho and Lantz (2015) utilize a CGE model to estimate the economic impacts of climate change on agricultural crops across provinces in Canada for the period between 2006 and 2051. They report gains for most Canadian provinces and for the nation as a whole in terms of induced output and welfare. Ochuodho and Lantz (2015) also argue that GDP and welfare impacts do not necessarily follow a similar direction due to climate change. For example, Alberta shows gains on both GDP (2.51%) and welfare (1.86%); Manitoba and Saskatchewan instead would experience gains on GDP (1.33% and 0.54% for Manitoba and Saskatchewan, respectively) but losses on welfare (-0.05% and -0.45% for Manitoba and Saskatchewan, respectively).

One major shortcoming of a CGE model is that the neo-classical assumptions made in the model are often charged as being incredible in many economic settings. In addition, as noted by Ochuodho and Lantz (2015), studies using CGE models usually do not capture the simultaneous impacts of climate change on the agricultural sector and other sectors. Instead, the estimates of potential impacts on agriculture such as crop yields and land value are often based on other previous research and applied to a CGE model as changes to the system, and then sectorial GDP impacts are calculated. Ignoring the simultaneous impacts may lead to imprecise estimates (Ochuodho and Lantz 2015).

An Integrated assessment model (IAM) can be used to build an interrelated system to link economic variables to biophysical response under the framework of climate change. An IAM can be defined as a model that combines scientific and socio-economic aspects of climate change for conducting an integrated assessment. An IAM is a mathematical computing model based on explicit assumptions on the built system about the atmosphere and oceans, land cover and land use, economic growth, fossil fuel emissions, population growth and technological change. IAMs have been used by several intergovernmental agencies and research institutions, such as IPCC, Interagency Working Group and National Round Table on the Environment and the Economy (NRTEE).[5] Common IAMs[6] include DICE (Dynamic Integrated Climate and Economy), PAGE (Policy Analysis of the Greenhouse Effect), and FUND (Climate Framework for Uncertainty, Distribution, and Negotiation).[7]

Paying the Price: The Economic Impacts of Climate Change for Canada by the NRTEE (2011), is the first study investigating the comprehensive economic costs of climate change in Canada. NRTEE (2011) employs the PAGE model to evaluate the costs of climate change for Canada. It is reported that climate change would impose costs from an average of $5 billion per year in 2020 to a range between $21 billion and $43 billion per year (equivalent to 0.8% to 1% of GDP) by 2050 to Canada.

Using IAMs, researchers are able to estimate the social cost of carbon (SCC) and evaluate tax and abatement policies. But the estimates are wide-ranging (Pindyck 2015). For example, using the DICE model, Nordhaus (2011) reported a SCC of $11 per ton. In contrast, Stern (2007) reported a SCC of $200 per ton using the PAGE model. The main reason for this difference is due to the different discount rates used in the model (Nordhaus used a higher discount rate compared to Stern's) (Pindyck 2015). IAMs are complicated and large systems (i.e., expensive to construct) and the results obtained from IMAs can be misleading and illusory. Pindyck (2015) and Pindyck (2013) argue that the knowledge about climate sensitivity and damage functions (e.g., the link between increasing temperature and GDP growth) is still quite limited. Different IAMs tend to have different assumptions in terms of functional forms, parameter values and discount rates. But these factors have large impacts

[5] The National Round Table on the Environment and the Economy (NRTEE) was an independent policy advisory agency to the Government of Canada.
[6] These three IAMs have been used by Interagency Working Group.
[7] For descriptions of the models, please see Nordhaus (2008), Hope (2006), and Tol (2002).

on the estimates. On the other hand, Wilkerson et al. (2015) argue that despite the limitations of IAMs, they can provide insights into the climate change problem that are not available through other analytical and decision-making models.

In summary, existing methods face formidable challenges in quantifying the effects of climate change. In comparison, A VARX (i.e., vector autocorrelation regression with exogenous variables) approach is an attractive alternative that is based on statistical regularities rather than relatively strong assumptions to examine the impact of climate change. It also enables the study of the overall effect of climate change on the economy while incorporating exogenous variables. The next section provides discussion of the VARX model.

2.2 A VARX Model

As mentioned earlier, the previous literature mainly uses production functions, profit functions, hedonic methods and mathematical modelling approaches (e.g., CGE models and IAM models) to estimate the economic impacts of climate change. However, these approaches are restricted by the underlying assumptions concerning the production structure and market clearing processes that are often not supported by empirical data (Foley and Michl 1999). In contrast, little economic theory is imposed *a priori* on a VAR (vector autocorrelation regression) model. Instead, the main idea of a VAR model is to assume that past and current values of data contain information to predict the future values of variables of interest. The important aspect of this approach is that the characteristics of the processes are based on statistical regularities rather than economic assumptions (Anon 2014). Previous literature showed that a parsimonious VAR approach often outperforms other complicated econometric models when it comes to forecasting (Gürkaynak, Kısacıkoğlu and Rossi 2013). For this reason, the VAR model has a long history of application in macro-economic problems (Anderson 1979; Sims 1980; Litterman 1986; Partridge and Rickman 1998; Jimenez-Rodriguez and Sanchez 2005; Love and Zicchino 2006; Erdil and Yetkiner 2009; Geamanu 2014; Nick and Thoenes 2014). A VAR model is able to incorporate structural change and adaptations. However, a VAR model is not a panacea. VAR models are limited in terms of the ability to provide structural explanations of economic causes (Anderson 1979).

In particular, VAR models have been used to address interesting research questions in the context of climate change. Policy proposals, such as a carbon tax, have been developed by the Intergovernmental Panel on Climate Change to mitigate global warming (IPCC 2007). Kato et al. (2013) perform a VAR analysis with output and employment data from nine industrialized countries to examine the short-term effect of a carbon tax on output and employment. Both output and employment are grouped into high-carbon intensive and low-carbon intensive industries, respectively. They impose a simultaneous policy shock using impulse response analysis in which a carbon tax is levied on high-carbon intensive industries and the tax revenue is reallocated to low-carbon intensive industries. Technically, a carbon tax is translated as a negative shock on high-carbon intensive sectors (for both output and employment) while a redistribution of the tax revenue is translated as a positive shock on low-carbon intensive sectors. They find that this policy introduces net gains in terms of output and employment.

Some recent works also make use of the VAR framework to analyze the direct impacts of climate change on economic activities, such as crop production and per capita GDP (see for example Baig and Amjad 2014; Janjua, Samad and Khan 2010). However, when climatic variables come into play, a VAR framework may be problematic. One issue of incorporating climate variables under a VAR framework is that all variables in a VAR assumed to be endogenous. Endogeneity implies variables included in the system can influence each other. But the relationship between climate variables and economic outcomes is not two-way at least for a small economy. For example, climate conditions, such as variations in temperature and precipitation would have an impact on agricultural production, but agricultural production in a small economy would have little effect on the climatic conditions. In a non-standard VAR, strictly exogenous variables may be included, but there is no way of simulating the time path or response of shocks to these exogenous variables on the system. In that sense exogenous variables have been introduced into a VAR strictly as control variables and not part of dynamic simulations and forecasts.

In order to deal with this issue, recent research has used VARX models to explore the impacts of climate change on economic variables. The difference between a VARX model and a VAR model is that a VARX model is able to differentiate between endogenous variables and exogenous variables. However, while a VARX model allows exogenous variables (and their dynamics) to appear as control variables in the system, it does not allow calculation of responses of the endogenous variables in the system to shocks in the exogenous variables. That is, a standard VARX model, like the standard VAR model, allows calculation of impulse responses only to *shocks to endogenous variables*. One improvement in this regard is the VARX model used by Fomby, Ikeda, and Loayza (2009; 2013), which develops a new econometric approach that allows for calculation of responses of *shocks to exogenous variables* of a VARX model to measure the marginal effect of exogenous shocks over the time path. In this thesis, I follow that approach.

Cuñado and Ferreira (2011) use a VARX model with country fixed effects to estimate the economic impact of floods (as exogenous variables) on GDP growth. GDP growth is examined and is disaggregated into agricultural GDP growth and non-agricultural GDP growth. They use 3,184 large flood events in 118 countries between 1985 and 2008 and denote floods in three different measurements including number of floods, average magnitude of floods and number of deaths by floods. For other endogenous variables, they include a corruption indicator, ethnic tensions, domestic credit and gross fixed capital formation to account for the differences across countries. Overall, they find that floods tend to have a positive effect on GDP growth, with a cumulative (for 10 years) average impact of 1.5 percent. When separate regressions are run for developing and developed countries, they find floods do not have a significant impact on GDP growth in developed countries. The authors also investigate the impact of floods on agricultural GDP and find that the impact is negative but insignificant in the first year but positive in the second. However, it is worth noting that

GDP is simply a measure of economic activity, not social wealth or welfare (Kousky 2012). In addition, GDP and welfare impacts may follow different directions due to some changes (e.g., climate change) to the economic system (Ochuodho and Lantz 2015; Zhai et al. 2009).

Using the same method, Fomby, Ikeda, and Loayza (2009; 2013) conduct a comprehensive cross-country analysis on the link between four types of natural disasters (i.e., droughts, floods, earthquakes and storms) and GDP growth. They set themselves apart from the literature by using bootstrap corrections and examine the different effects of severe vs. moderate natural disasters. In particular, Fomby, Ikeda, and Loayza (2013) include six endogenous economic variables (i.e., capital formation, inflation, trade openness, government consumption, financial depth and GDP/agricultural GDP/non-agricultural GDP). For exogenous variables, other than natural disaster variables, they also include the world's GDP per capita and the terms of trade (TOT) to capture interactions among countries, shifting in the world business cycle and the demand for a country's exports (Fomby, Ikeda, and Loayza 2013). The main findings conclude that natural disasters have stronger effects on developing than on developed countries. Severe disasters often bring about worse impacts than moderate effects do. Droughts have an overall negative effect on GDP growth. But floods tend to induce positive effects on GDP growth. Earthquakes tend to have a positive effect while storms tend to have a negative effect on GDP growth. The impacts due to earthquakes and storms are weaker in terms of magnitude and significance. The authors also argue that pooling cross-country data can mask important country-specific differences and only present mean responses (by averaging repeated experiences). Individual country (or region) analysis will be useful to account for this point.

There is a relatively rich literature on the economic impacts of natural disasters compared to that due to climate change. However, economic research in this field is still considered in an early stage and researchers have not come to a consensus (Fomby, Ikeda, and Loayza 2013). As mentioned, climate change could alter the frequency, intensity, spatial extent, duration and/or timing of extreme weather events. But natural disasters only represent one aspect of climate change. In contrast, temperature and precipitation are the main indicators for climate change. Analyzing the economic impact due to climate change from temperature and precipitation shocks in a sense provides a net response of GDP growth to climate change, which presents a broad picture of the issue.

2.3 Economic Growth Theory

This section provides an overview of the determinants of economic growth and related literature and it mainly focuses on the Canadian context to help us decide which variables to incorporate into the model employed in this study. The Solow (1956) model is the standard theoretical model in economic growth theory. This neoclassical model assumes diminishing returns to capital and labour. Economic growth is a process of capital accumulation and is sustained by exogenous technological development. A major shortcoming of the Solow model is that it lacks explanation of the sources of technological change. Unsatisfied with the assumption of exogenous technological change, the Solow model has been developed into models of endogenous growth driven by factors including human capital, technology and knowledge (Lucas 1988; Romer 1990; Grossman and Helpman 1991).

The main empirical model of the economic growth literature is due to Barro (1991). In the Barro (1991) model, annual and multi-year average growth rates of per capita real GDP is regressed on a set of determinants based on theory for ninety-eight countries in the period from 1960 to 1985, while keeping constant other variables such as trade openness and government consumption (as a share of gross domestic product). Barro (1991) reports that the growth rate of real GDP per capita is positively related to initial human capital and political stability, but inversely related to the initial level of real GDP per capita, government consumption and market distortions. Human capital is the key input that underlies technological progress. Poor countries tend to grow faster if they have a high human capital level.

A large empirical literature has also investigated economic growth across countries and across regions within a country. It is noteworthy that variables investigated are different in various research contexts (e.g., international versus within country studies). Overall, in cross-country study, there is an emphasis on the variables that can account for different institutional and political contexts for different countries. The key growth determinants for cross-country studies include human capital, inflation, trade openness, government consumption, financial depth and the investment rate (e.g., Mankiw, Romer and Weil 1992; Levine, Loayza and Beck 2000; Fomby, Ikeda, and Loayza 2013).

For the purpose of this analysis, we focus on the economic growth literature in Canada, which in turn aids our choice of variables and validation of our empirical model by examining the results. A general theme in the Canadian literature is to identify the determinants of the regional economic growth and to analyze whether there is the presence of convergence (i.e., regions with relatively low initial incomes tend to grow faster to catch up with the other regions) for regions in Canada (Matejovsky, Mohapatra and Steiner 2014). There are also many qualitative studies that mainly review relevant literature for OECD countries to gain insights for Canadian policy. For example, Coulombe (1999) argue that human and physical capital tend to accumulate more quickly in poor regions, while the disparities between rich and poor regions are due to industrial structure and institutional and political context (e.g., governmental redistribution programs). This argument is also supported by DeJuan and Tomljanovich (2005) who state that government redistribution programs (i.e., tax on richer provinces and transfer to poorer provinces) help the convergence process in Canada. Coulombe and Tremblay (2009) review the literature on human capital and growth for OECD countries and argue that human capital has a significant effect on economic growth.

The quantitative studies are similar in terms of estimating a growth regression following Barro (1991). These Canadian studies are different in terms of the set of determinants chosen to explain regional growth. For example, Coulombe (2000) analyzes the role of urbanisation by using the conditional convergence model for the relative change of per capita income across Canadian provinces. Urbanization is denoted as the share of the population living in urban area in a province relative to the provincial average. The author reports that the provinces have converged at a rate of about 5% per year. Coulombe (2000) also notes that Alberta is Canada's major oil producing province and the oil-price shock in 1973 was a disturbance in the convergence process between Alberta and the other provinces.

Lee (1996) studies provincial data from 1968 to 1992 in Canada. The author divides the time series into three sub-periods: 1968-1976, 1976-1984 and 1984-1992 to mitigate degrees of freedom problems. Lee (1996) finds that there is a tendency for poorer provinces to catch up to richer provinces, especially when industrial structure, human and physical investments are accounted for (i.e., conditional convergence). In addition, inter-provincial migration and public investment tend to have a positive impact on provincial economic growth while government consumption is inversely correlated with economic growth. Lee (1996) also argues that it is impossible to eradicate the disparities among Canadian provinces, due to the fact that key aspects in the industrial structure differ from resource endowments, climate and preference differences. These aspects are beyond the control of government.

A study from Coulombe and Tremblay (2009) also find a similar result to Lee (1996) on migration that interprovincial migrants have a positive effect on the mean skill level of labour in the host province. However, Helliwell (1996) holds a different opinion that interprovincial migration happened as more people from the poorer provinces are attracted by the relatively high incomes and low unemployment rates in the richer provinces. This may in turn have a negative impact on economic growth in the richer provinces and contribute to the process of convergence. Coulombe (2003) conducted a convergence regression test for Canadian provinces between the periods from 1981 to 1999. He found that both international and interprovincial trade tend to have a positive and significant effect on regional GDP per capita, productivity and employment.

Recent work by Matejovsky, Mohapatra and Steiner (2014) provides a summary of the Canadian economic growth literature. They distinguish their work from the existing literature by testing the role of entrepreneurship on regional growth. They report that entrepreneurship has a positive effect on growth. Other variables in the regression model include the employment rate (a positive effect), net trade (insignificant effects), migration (a negative effect) and minorities (a positive effect).

To date, no existing Canadian study that we are aware of investigates the relationship between climate change and economic growth. This study focuses on how climate change affects Alberta's economic growth. In contrast to other Canadian literature, this study only examines economic growth conditioned on climate change for a single provincial economy of Alberta. Two groups of growth determinants are included to build an economic system for the province. The first group of variables represents domestic conditions and policies; the second group of determinants captures the effect of external conditions that affect the Alberta economy. Details on the variables are presented in the Data and Methods section (Section 3).

2.4 Alberta

2.4.1 Alberta's Economy

This section provides an overview of Alberta's economy and climate. Alberta is the fourth-most populous province with a population of 4,160,044 as of January 2, 2015 in Canada (Statistics Canada 2015). The population is not distributed evenly across the province. There are 19 Census Divisions (CD)[8] in Alberta. The capital city, Edmonton is in CD11 and the largest city, Calgary is located in CD 6. Populations in these two CDs account for about 70% of total population in Alberta in 2013 (Alberta Treasury Board and Finance 2015). Regional economic activity is highly correlated with its population size in Alberta. Edmonton and Calgary metropolitan areas accounted for 60.4% of provincial GDP in 2009 (Statistics Canada 2015).

Alberta has led the nation in economic growth over the past 20 years, with an average annual GDP growth of 3.5% per year between 1993 and 2013 (Government of Alberta 2015a). Alberta is considered a resource-based economy. In 2013, total exports of goods in Alberta

[8] According to Statistics Canada, a Census Division is a group of neighbouring municipalities for the purpose of regional planning and managing common services

were $103.7 billion (compared to $338.2 of total GDP), among which crude petroleum alone accounted for about 62.1% of total exports (Government of Alberta 2015a). Indeed, the energy sector is Alberta's driving economic force. But the structure of the economy has become more diverse over the past three decades. For example, the energy sector accounted for 36.1% of total GDP in 1985, while this figure dropped to 23.1% in 2013. During the same time, the share of agricultural GDP relative to provincial GDP also decreased from 3% to 2%. Other sectors, such as tourism, manufacturing as well as retail and wholesale trade have increased during the period (Government of Alberta 2015a).

The Agricultural industry in Alberta consists of crop production, animal production, fishing, hunting and trapping activities and relevant support services. Alberta farms produce an abundant supply of agricultural commodities including beef, cattle, wheat, canola, barley, hogs and milk (Government of Alberta 2015a). Although agriculture in Alberta only accounts for a small share of total GDP (Government of Alberta 2015a), it is considered a major economic driver in the region (Kulshreshtha 2011). At the national level, the agricultural sector directly and indirectly employed over two million people (AAFC 2012). Alberta's agricultural sector is also essential for the local as well as national food supply system representing 22.4% of the national industry total (Statistics Canada 2015). Crop production is estimated at $5.9 billion (22.4% of Canadian crop production) and livestock production at $6.4 billion (22.4% of Canadian livestock production) (Statistics Canada 2015). On the other hand, Agriculture is the largest water user in Alberta. In 2014 it accounted for about 65% of total provincial water use (Faramarzi et al. 2015). Climate change alters water availability and the hydrology of the region, which could pose threats and uncertainty to Alberta's agriculture, as well as other sectors of the economy.

2.4.2 Alberta's Climate

Alberta is Canada's second most western province and the fourth largest province with an area of about 666,000 km^2. It is located between 49-60 °N and 110-120 °E. The altitude varies from 152 metres (above sea level) in the Slave River-Wood Buffalo National Park in the northeast to 3,747 metres in the Rocky Mountains along the south-western border. Although most parts of Alberta could be classified as semi-arid, its climate varies considerably with temperature and precipitation. Temperatures are generally higher in southern than northern Alberta. In January, the daily mean temperature ranges from -24°C in the north to -10°C in the south. In July, the average daily temperature ranges from 13°C in the north to 18°C in the south (Government of Alberta 2015b). The extreme temperatures can go down to -54°C in the winter for northern Alberta and go up to 40°C in southern Alberta (Government of Alberta 2015b). Overall, precipitation is the highest along the Rocky Mountains and into the west central part of the province (Government of Alberta 2015b). Average annual precipitation ranges from 300 mm in the southeast to 600 mm in the Mountains (Alberta Environment 2008).

Several changes of climate in Alberta have been observed. Surface air temperatures in Alberta increased from 1.3 to 2.1 °C over the period from 1895 to 1991 (Shen et al. 2005). The average temperature increased by 1.6°C between 1953 and 2005 in the Prairies[9] (Wheaton and Kulshreshtha 2010). There are trends toward fewer days with extreme low temperature but more days with extreme high temperature, longer frost-free days and growing degree days (Wheaton and Kulshreshtha 2010). These trends are projected to continue for Alberta's future climatic conditions (Kulshreshtha 2011). At the same time, the pattern of precipitation tends to be more uncertain. It is reported that precipitation during May to August in Alberta increased by 14% from 1901 to 2002 (Shen et al. 2005). In contrast, Wheaton and Kulshreshtha (2010) report that precipitation during the spring season had shown decrease in central Alberta; according to the projections by Barrow (2010), the annual mean precipitation would decrease from 0% to 10% across the Prairies.

3. Data and Methods

We use a quarterly dataset including average maximum temperature, total precipitation,

[9] The Prairies is a region in western Canada. It comprises the provinces of Alberta, Saskatchewan, and Manitoba.

Table 1: Description of Variables Used in VARX Model, 1986 Q1 – 2007 Q4

Variable	Definition	Source
GDP	Real GDP at Basic Prices for all industries in Alberta (Chained $ 2007)	The Conference Board of Canada
Agr. GDP	Real agricultural GDP at Basic Prices in Alberta (Chained $ 2007)	The Conference Board of Canada
Non-agr. GDP per capita	Real non-agricultural GDP at Basic Prices in Alberta (Chained $ 2007)	The Conference Board of Canada
Fixed capital formation	Gross fixed capital formation as percentage of GDP in Alberta (Millions, Chained $ 2007)	The Conference Board of Canada
Unemployment rate	Unemployment Rate in Alberta (%)	The Conference Board of Canada
Trade openness	The sum of exports and imports as percentage of GDP in Alberta (Millions, Chained $ 2007)	The Conference Board of Canada
Net migration	Net provincial migration in Alberta (persons)	The Conference Board of Canada
Oil price	West Texas Intermediate (WTI) oil price ($ per barrel)	US Energy Information Administration
World GDP per capita	Real World GDP per Capital (Chained $ 2005)	World Development Indicators
Temperature	Average maximum temperature (°C)	Faramarzi et al. (2015)
Precipitation	Total precipitation (mm)	Faramarzi et al. (2015)

and seven macroeconomic variables (see Figures 16 to 25 in Appendix D for the plots of the raw data). We trace the response of agricultural and aggregate GDP growth to two climatic shocks based on quarter-to-quarter fluctuations in temperature and precipitation for Alberta, Canada. Our dataset covers the period from 1986 to 2007. The data for this study are from five sources. Table 1 presents the definition and the data source for each variable. In our VARX model defined in Equation 4 (discussed below), we have five endogenous variables, including growth rates of total GDP, agricultural GDP and non-agricultural GDP, fixed capital formation, unemployment rate and trade openness, and net migration (in levels) (see Figures 26 to 34 in Appendix D for the plots). The discussion below outlines the rationale for the selection of climate and economic variables.

3.1 Economic Variables

Following Fomby, Ikeda and Loayza (2013), we define three growth variables: the growth rates of real GDP per capita, real agricultural GDP per capita and real non-agricultural GDP per capita. All these growth rates are measured as the log difference of per capital output (in 2007 Canadian dollars), where per capita output is obtained by dividing output by the total population. Population information is based on Statistics Canada (Canadian Socio-economic Information Management System (CANSIM) Table 051-0005). Quarterly data of the three GDPs, fixed capital formation, unemployment rate, trade openness and net migration in Alberta are obtained from the Conference Board of Canada. These economic variables are based on our overview of determinants of economic growth in Canada (see Literature Review section for more discussion) and data availability aiming to form the endogenous economic system for Alberta.

Stern (2010) and Aghion and Howitt (2009) argue that most of the literature on energy and economic development discuss how development affects energy use and not the other way around. In this study, oil price is included in our VARX framework for two reasons. First, oil price (an input factor) is an important factor of the consumption of energy. Second, Alberta is an energy-based province with the largest share of GDP due to the energy sector. Thus, to capture external interactions with Alberta's economy, we also include two exogenous macroeconomic variables: oil price and the world GDP per capita. Oil price is based on the US Energy Information Administration. Annual world GDP per capita is obtained from the World Development Indicators of the World Bank and we convert it to a quarterly series by applying cubic spline interpolation (i.e., 'cubic match last'[10] within EViews 8). Most of the economic variables are measured as the log difference due to the presence of unit roots and for ease of interpretation. Discussion of unit root tests follows in the Diagnostic Tests section.

[10] The fundamental idea of cubic spline interpolation is to draw smooth curve passing through each of the observations to convert data from annual to quarterly. Under 'cubic match last', the annual data for a specific year becomes the data for the last quarter of the same year, and a cubic piecewise polynomial function draws a seamless curve connecting the observations.

3.2 Climatic Variables

Table 2.1: Descriptive Statistics of Variables in Levels, 1986 Q1 – 2007 Q4

Variable	Mean	Std.Dev.	Min	Max
GDP per capita	59,065	7,886	46,896	72,527
Ag GDP per capita	1,018	133	628	1,233
Non-Ag GDP per capita	58,047	7,846	45,820	71,428
Fixed capital formation	0.2380	0.0564	0.1547	0.3591
Unemployment rate	0.0660	0.0208	0.0320	0.1053
Trade openness	0.23	0.05	0.08	0.32
Net migration	12345	20958	-56696	66916
Oil price	36.28	14.99	15.65	92.74
World GDP per capita	6304	612	5364	7647
Temperature	7.09	10.24	-8.97	21.70
Precipitation	109.67	54.69	34.57	211.26
Weighted Temp.	70.51	70.89	-40.24	203.03
Weighted Prec.	892.53	522.05	195.91	2077.10

Table 2.2: Descriptive Statistics of Variables in Growth Rates, 1986 Q1 – 2007 Q4

Variable	Mean	Std.Dev.	Min	Max
GDP growth	0.0039	0.0167	-0.0464	0.0458
Agr. GDP growth	0.0049	0.1111	-0.5384	0.3100
Non-agr. GDP growth	0.0039	0.0171	-0.0500	0.0469
Fixed capital formation growth	0.0061	0.0443	-0.1383	0.1169
Unemployment rate growth	-0.0114	0.0593	-0.1647	0.1554
Trade openness growth	-0.0100	0.1188	-0.4783	0.2849
Oil price growth	0.0090	0.1430	-0.4306	0.3533
World GDP per capita growth	0.0041	0.0024	-0.0012	0.0080

Data Source: The Conference Board of Canada (2015); US Energy Information Administration (2015); World Development Indicators (2015); Faramarzi et al. (2015)
Note: There are 88 observations for each variable.

For climatic variables, daily temperatures and precipitation are available at a station level across the province. However, our economic variables are quarterly and at a provincial level. In order to be consistent with the economic variables, the two climatic variables used in our model are the population-weighted[11] average maximum temperature and total precipitation for each quarter at a provincial level. Temperature and precipitation are the common

[11] Population-weighted climate variables are also used by Dell et al. (2012).

indicators of climatic conditions used in the literature of climate impacts on economic growth under economy-wide analysis (e.g., Dell et al. 2012; Moore and Diaz 2015). Total precipitation presents water availability for production as well as the potential risk of floods. Similar average temperatures may result from different temperature variations (Schlenker and Roberts 2009). Average maximum temperature is a better alternative to average temperature to capture crops' sensitivity to extreme temperatures and indicates the potential occurrence of droughts. The climate conditions as well as economic activities are not homogenously distributed across the province. Thus, it may be inappropriate to simply use the average provincial climatic conditions for the analysis. In order to better understand the impacts of climate change on the economic growth, we use population-weighted temperature and precipitation. We weight our climatic variables by the population of each Census Division (CD) from the previous year and then convert them to a provincial level.[12] The rationale behind this practice is that the distribution of population is highly correlated with GDP for each CD.

3.3 Summary Statistics

We plot the variables used in our VARX model defined by Equation 4 (see Figures 26 to 34 in Appendix D). The figures illustrate some degree of persistence and indicate the appearance of heteroscedasticity. However, considering heteroscedasticity in a VARX system is challenging. Therefore, potential autoregressive conditional heteroscedastic (ARCH) effects are out of scope of and not investigated in this study.

Descriptive statistics of the variables are presented in Table 2.1 and Table 2.2. We highlight some key points here. During the period between 1986 Q1 and 2007 Q4, the mean GDP per capita was \$59,065, while the agricultural GDP per capita (i.e., \$1,018) is much lower. However, as for growth rates, on average, quarterly agricultural GDP had been growing at a faster rate (i.e., 0.49%) compared with the GDP growth rate (i.e., 0.39%) and non-agricultural GDP growth rate (i.e., 0.39%). Due to the small share of the agricultural

[12] We used population of each CD as our weight, because GDP data are not available at a regional level. We used the information from last year, so that the climatic variables can still be considered as exogenous.

sector relative to total GDP, statistics for GDP and non-agricultural GDP are quite similar. The average (maximum) temperature is 7.09°C, with a minimum of -8.97°C and a maximum of 21.70°C and the average (total) precipitation is 109.67mm, with a minimum of 34.57mm and a maximum of 211.26mm.

As indicated in Table 3, the correlation between the growth rate of total GDP with population-weighted temperature and precipitation is -0.2619 and -0.2166, respectively (see the scatterplot in Figure 35 in Appendix D). The correlation between the growth rate of non-agricultural GDP with population-weighted temperature and precipitation is -0.2703 and -0.2295, respectively (Figure 37 in Appendix D). In contrast, the correlation between the growth rate of agricultural GDP with population-weighted temperature and precipitation is positive—0.0868 and 0.1243, respectively (Figure 36 in Appendix D). In addition, the correlation between the growth rates of the non-agricultural sector with the agricultural sector is quite low (i.e., -0.0465). We suspect that the climatic shocks may produce different dynamic effects on different sectors of the economy. The correlation between temperature and precipitation is 0.8479, indicating that warming has been associated with more precipitation.

Table 3: Pairwise Correlation among Variables in VARX Model, 1986 Q1 – 2007 Q4

	GDP growth	Agr. GDP growth	Non-agr.GDP growth	Fixed capital growth	Unemployment growth	Trade openness growth	Net migration	Oil price growth	World GDP growth	Temperature	Precipitation
GDP growth	1										
Agr. GDP growth	-0.0039	1									
Non-agr. GDP growth	0.9933	-0.1183	1								
Fixed capital growth	-0.0084	-0.1788	0.1252	1							
Unemployment growth	-0.2481	0.0469	-0.2534	-0.1766	1						
Trade openness growth	-0.2578	0.0375	-0.2623	-0.1021	-0.0442	1					
Net migration	0.0381	-0.1113	0.0508	0.0219	-0.0684	0.1074	1				
Oil price growth	0.2088	0.0540	0.2005	-0.1109	-0.1111	-0.3278	0.0165	1			
World GDP growth	0.1426	0.0081	0.1420	0.1009	-0.3290	-0.1673	-0.0412	0.2093	1		
Temperature	-0.2619	0.0868	-0.2703	-0.0009	-0.0115	0.0899	0.1737	0.1670	0.0577	1	
Precipitation	-0.2166	0.1243	-0.2295	0.0065	0.0484	0.0544	0.2675	0.1898	0.1095	0.8479	1

Data Source: The Conference Board of Canada (2015); US Energy Information Administration (2015); World Development Indicators (2015); Faramarzi et al. (2015)

Note: There are 88 observations for each variable.

Table 4: Unit Root Tests for Variable in VARX Model

Variable	With Intercept		With Intercept and Trend		1^{st} Order Difference	
	ADF	PP	ADF	PP	ADF	PP
GDP per capita			0.0809	0.0994	0.0000	0.0000
Ag GDP per capita			0.0000	0.0000	0.0000	0.0001
Non-Ag GDP per capita			0.0935	0.1055	0.0000	0.0000
Fixed capital formation	0.9679	0.9929			0.0000	0.0000
Unemployment rate			0.5684	0.5854	0.0000	0.0000
Trade			0.1643	0.1372	0.0000	0.0000
Net migration			0.0000	0.0000	0.0000	0.0000
Oil price	0.7078	0.7038			0.0000	0.0000
World GDP per capita	0.8722	0.8698			0.0000	0.0000
Temperature	0.0000	0.0000				
Precipitation	0.0000	0.0000				

Note: ADF and PP stand for the augmented Dickey-Fuller test and the Philips-Perron test, respectively. The figures reported in the table are P values.

3.4 Diagnostic Tests

3.4.1 Unit Root Tests

The VARX model is dependent on the assumption of stationarity of the variables. The augmented Dickey-Fuller (ADF) test and the Philips-Perron (PP) test are utilized to determine the stationary form of the variables in the VARX model. The unit root tests are dependent on the deterministic parts (i.e., regression forms) of the unit root test equations (Fomby, Ikeda and Loayza 2013). Including unnecessary deterministic trends lead to lost power, while missing necessary trends biases the test in favour of the null hypothesis of a unit root (Elder and Kennedy 2001). Based on Verbeek (2012) and Fomby, Ikeda and Loayza (2013), we test the significance of the trend for our variables by testing the significance of the intercept in the following the second-order autoregressive process (i.e., AR (2)) for the above 12 series.

$$\Delta Z_t = \alpha + \beta Z_{t-1} + \gamma \Delta Z_{t-1} + \varepsilon_t \qquad (1)$$

where Z_t denotes the variables of VARX model and Δ is the first-difference operator. A second-order autoregression, AR(2), is aming to ensure that the residuals of the above equation are white noise, thus the OLS t-statistics would be appropriate to test for the presence or absence of a trend. If α is significantly different from zero (at the 0.05 level), we conclude that a deterministic trend is present in the level of Z_t.

Based on the tests, six variables including GDP per capita, agricultural GDP per capita, non-agricultural GDP per capita, unemployment rate, trade openness and net migration are found to have a time trend, whereas the tests for the rest of the varables indicate absence of such deterministic trends. Therefore, we proceed with the ADF and PP tests by including an intercept and a deterministic trend for the series with trends, while only including an intercept for the series without trends.

In Table 4, we summarize the results of tests based on the 0.05 level of significance from the ADF and PP tests as follows:

- Agricultural GDP per capita and net migration are trend stationary;
- GDP per capita, non-ag GDP per capita and fixed capital formation, trade openness, unemployment rate, oil price and the world GDP per capital clearly fail to reject the null hypothesis of nonstationarity. After first differencing, they appear to be stationary.
- Temperature and precipitaion are stationary.

Since most of the economic series are not stationary in their levels, we decided to measure all the economic variables but net migration as log differences to have a stationary form and also to apply a very straight-forward interpretation, namely percentage change or growth rate to each log differenced variable. Net migration is measured in levels because of the negative values contained in this variable. For climatic variables, temperature and precipitation are entered in the model in levels.

Table 5: Lag Stucture Selection for VARX Models

VARX Model		Number of Lags			
		p = q= 1	p = q= 2	p = q= 3	p = q= 4
GDP growth	AIC	-11.4995	-11.4915	-11.7544*	-11.513
	SBC	-10.0823*	-9.36573	-8.92006	-7.97002
Agr. GDP growth	AIC	-7.25805	-7.22336	-7.40322	-7.41989*
	SBC	-5.84086*	-5.09758	-4.56884	-3.87691
Non-agr. GDP growth	AIC	-11.4818	-11.4709	-11.7283*	-11.5102
	SBC	-10.0646*	-9.34512	-8.89391	-7.96722

Note: AIC and SBC stand for Akaike's information criterion and Schwarz's Bayesian information criterion, respectively. p and q represent the number of lags for the endogenous and exogenous variables, repectively. * indicates the mimumum AIC and SBC.

3.4.2 Lag Structure Selection

To determine the lag structure of the VARX model, we employ two well-known model selection critera: Akaike's information criterion (AIC) and Schwarz's Bayesian information criterion (SBC).

AIC (Akaike 1973) is given by

$$AIC = \log \frac{1}{N} \sum_{i=1}^{N} e_i^2 + \frac{2K}{N} \tag{2}$$

and SBC (Schwarz 1978) is given by

$$SBC = \log \frac{1}{N} \sum_{i=1}^{N} e_i^2 + \frac{K}{N} \log N \tag{3}$$

where N is the number of observations and K is the number of parameters in the VARX model.

We denote p and q as the number of lags to be included for the endogenous and exogenous variables, respectively. For the sake of parsimony, we specify the maximum number of the lags to be four and set p equal to q across models with three different GDP growth rates. Clearly, the SBC tends to favour more parsimonious models than the AIC, since a larger penalty is imposed by the SBC for increasing the number of lags. We summarize the information of the AIC and the SBC in Table 5. The results are mixed. SBC statistics suggest the selection of p = q= 1, while the AIC suggests p = q= 4 for the model with agricultural GDP growth rate and p = q= 3 for models with total GDP growth rate and non-agricultural GDP growth rate. Since the purpose of this study is to analyze the dynamic effects of climate change, we decide to use the lag length of four for all the models. The justification of doing so is two-fold. Firstly, since we use quarterly series; a longer lag length provides richer dynamics (four quarters include information over a two-year period) and secondly, it will simplify interpretation and comparision with the same structure of lag length across the models.

3.5 Econometric Method

We specify a VARX model as follows:

$$Y_t = \alpha + \beta_1 Y_{t-1} + \beta_2 Y_{t-2} + \beta_3 Y_{t-3} + \beta_4 Y_{t-4} + \gamma_0 X_t + \gamma_1 X_{t-1} + \gamma_2 X_{t-2} + \gamma_3 X_{t-3} + \gamma_4 X_{t-4} + \varepsilon_t \quad (4)$$

where Y_t represents the (5×1) vector of endogenous variables, including growth rates of total GDP, agricultural GDP and non-agricultural GDP, fixed capital formation, unemployment rate and trade openness, and net migration (in level). X_t denotes the (4×1) vector of exogenous variables, including growth rates of oil price and per capita world GDP, total precipitation and average temperature (in level). α is the (5×1) vector of intercepts; β_i's are the (5×5) matrices of coefficients ; γ_j's are the (5×4) matrices of coefficients and ε_t is the (5×1) vector of errors.

Sims (1980) and Sims, Stock and Watson (1990) argue that the goal of a VAR is to analyze the interrelationships among the variables, rather than to determine the parameter estimates. In addition, the variables in a VAR system are likely to be highly correlated. T-tests on individual coefficients are not reliable (Enders 2014). For these reasons, the coefficient estimates obtained from the model are therefore difficult to interpret and they are usually not used for interpretation. Instead, impulse response functions (IRFs) are used to trace out the response of the shocks on the variables contained in the VAR system. Since some of the correlation coefficients between the error terms in Equation (4) are deemed to be significant,[13] we follow the usual procedure to obtain the IRFs for our endogenous variables using a particular ordering (i.e., the orthogonalized impulse response functions). The orthogonalized impulse response functions define the response of three types of GDP growth from one-unit standard deviation increase in the endogenous variables over the time path.

Basically, the orthogonalized impulse response functions assume that the variables earlier in the ordering affect the subsequent variables contemporaneously and with a lag; while the variables later in the ordering only affect the preceding variables with a lag. Based on Granger Causality Tests[14] and relevant literature, we use the following ordering for the endogenous variables: trade openness, GDP, unemployment rate, fixed capital formation and net migration. After estimating Equation (4),[15] IRFs are employed to trace out the effects of shocks on the endogenous variables and the mean responses of shocks on the exogenous variables are computed based on the following Equations (5 through 8). The ordering only affects IRFs not the calculation of the response of GDP growth to the exogenous shocks defined by Equation 8. Equation 8 is to calculate the mean response or marginal effect of GDP growth to the exogenous shocks (i.e., one standard deviation to the exogenous variables) over the time path not traditional IFRs.

Equation (4) can be written in a more compact form as

$$(\mathrm{I} - \beta_1 L - \beta_2 L^2 - \beta_3 L^3 - \beta_4 L^4) Y_t = \alpha + (\gamma_0 + \gamma_1 L + \gamma_2 L^2 + \gamma_3 L^3 + \gamma_4 L^4) X_t + \varepsilon_t \tag{5}$$

where L is the lag operator. Equation (5) can be represented using lag operations (L) as

$$\Phi(L)\, Y_t = \alpha + \Gamma(L)\, X_t + \varepsilon_t \tag{6}$$

where Φ and Γ are each lag polynomials of order L.

Inverting Equation (6) yields the multiplier form as

$$Y_t = \Phi(L)^{-1} \Gamma(L) X_t + \Phi(L)^{-1} \varepsilon_t \tag{7}$$

[13] As recommended by Enders (2014), if the correlation coefficient is greater than 0.2, the correlation is considered to be significant. An ordering of variables is used to obtain the IRFs. The results are presented in Appendix B.
[14] See Appendix B for details.
[15] It is estimated using STATA 12. See details in Appendix A. See Stata code in Appendix F.

Using Equation 7, the mean responses of GDP growth to the exogenous shocks defined by Ψ[16], can be computed by taking the derivative of Y with respect to X as

$$\frac{\mathrm{dy}}{\mathrm{dx}} = \Psi = \Phi(L)^{-1}\Gamma(L) \tag{8}$$

Equation 8 is at the crux of our empirical analysis. It defines the impacts on GDP growth from a one standard deviation increase in the exogenous variables. To assess uncertainty and draw inferences, the Monte Carlo procedure[17] based on asymptotic theory is used to construct 90% confidence intervals around the response curve and to identify the significances of the responses.

4. Results and Discussion

This section presents the results of the VARX model presented in the previous section. The main focus of this study is to trace the response of GDP growth to two climatic shocks (i.e., temperature and precipitation shocks).[18] We first present results on the link between GDP growth and oil prices as a way to validate our VARX system. Then we proceed to report on the economic impacts of GDP growth due to temperature and precipitation shocks using population-weighted climate variables. After this, for a comparison, the results using unweighted climate variables are presented. Lastly, we conduct simulations based the VARX model under different climate change scenarios to investigate the economic impacts of temperature-precipitation interactions.

For each climatic shock, we depict the mean responses of per capita total GDP growth and of two types of sectorial GDP growth (i.e., agricultural and non-agricultural GDP growth) to the climatic shocks. The solid line in the figures denotes the mean response curve and the two dotted lines represent the 90% confidence interval. We also report on the cumulative effects (as a summation of mean responses for each period) for a period of four years (16 quarters) starting from the climatic shocks.

[16] It is estimated using MATLAB 2014. See MATLAB code in Appendix F.
[17] However, it is noted by Sims and Zha (1999) and Benkwitz, Neumann and Lütekpohl (2000) that confidence intervals computed by asymptotic theory may not be reliable for a small sample.
[18] We present the model estimates and selected IRFs of the endogenous variables in Appendix A and Appendix E.

A VARX model is promising at forecasting but it is not capable of explaining the direct factor(s) leading to the path of the adjustment due to the climatic shocks. In order to better understand our results, we include relevant literature into the discussion for each climatic shock and we focus on the agricultural sector.

4.1 Oil Price Shocks

Given the fact that Alberta is an energy-based economy, oil prices have been considered as an important factor to the provincial economic growth. Prior to presenting our findings for the main focus, we show the response of GDP growth to the oil price shocks. This can be used to validate the model specification and see if the relationship is reasonable. Figure 1 depicts the dynamic path of GDP growth to oil prices shock. Oil prices have positive effects on the growth rates of total GDP, agricultural GDP and non-agricultural GDP. The positive impacts are not significant until the third quarter after the oil price shock for both total GDP growth and agricultural GDP growth, and the fourth quarter for non-agricultural GDP growth, indicating the presence of delayed effects. The positive effect peaks three quarters after the event for agricultural growth, and seven quarters after for GDP growth and non-agricultural growth. The reasons for the peak coming earlier for agricultural growth are likely that higher oil prices indicate higher demand for both agricultural commodities and oil products (both from domestic and international markets), while new oil projects may take more time to plan and build. The positive relation is not surprising as the energy sector accounts for the largest share of total GDP; oil prices have significant impacts on the energy sector and the energy sector will carry spill-over effects on to the other sectors (e.g., the service and transportation sectors) in the economy.

The response curves show long decay rates, meaning that the effects of oil price shocks on Alberta' GDP growth tend to die out slowly. As indicated in Table 6, oil prices tend to have longer lasting effects (in terms of significance) on total GDP growth and non-agricultural GDP growth than on agricultural GDP growth. The effect is still significant after 16 quarters from the oil price shock for total GDP growth and non-agricultural GDP growth. Also, the cumulative effect is larger for agricultural GDP growth (19 percentage points (pp)) than for total GDP growth (3 pp). This may be because increased oil price is an indicator of good macroeconomic conditions, with positive impacts on agricultural production. The agricultural sector only accounts for a small share of total GDP and is more sensitive to oil prices. In summary, the positive relationship between oil prices and GDP growth is as expected in the model.

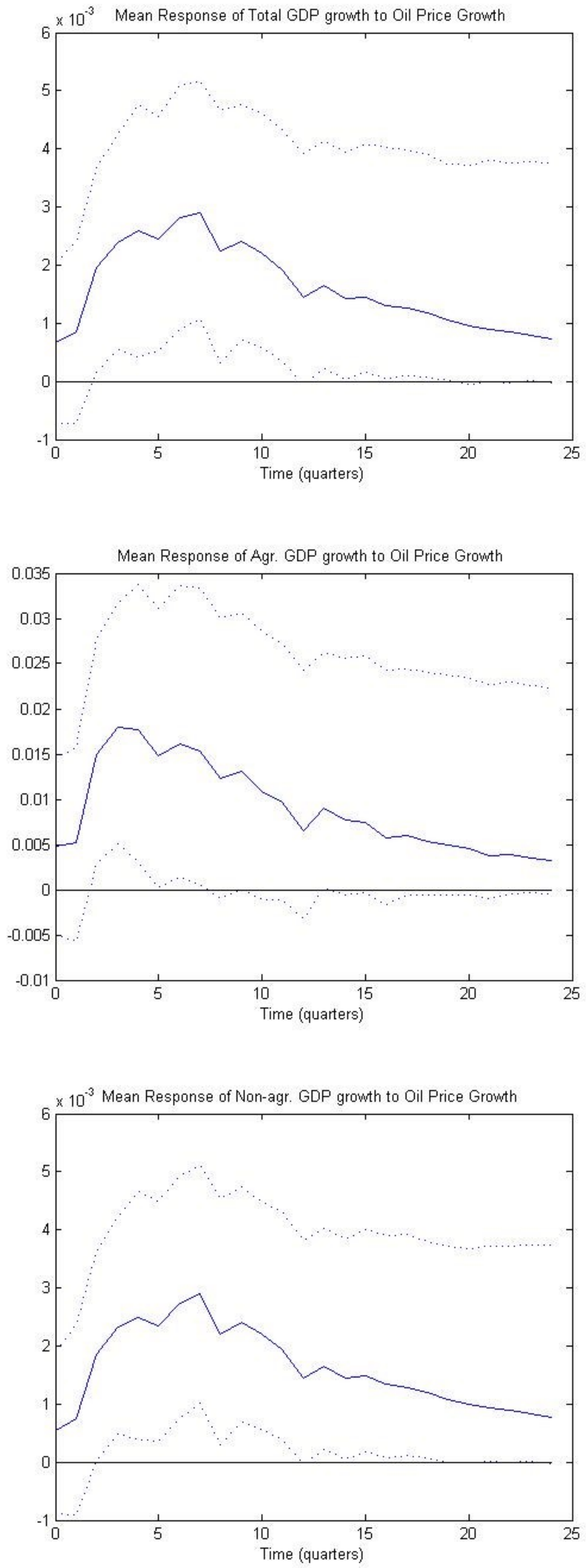

Figure 1: Response[19] of GDP Growth to Oil Price Shock

[19] The response of total GDP growth/agricultural GDP growth/non-agricultural GDP growth to shocks in the exogenous variables (Figure 1 to Figure 9) is calculated based on Equation 8, which defines the impacts on GDP growth from one standard deviation increase in the exogenous variables (i.e., oil price, temperature and precipitation) over the time path.

Table 6: Mean Response of GDP Growth to Oil Price and Climatic Shocks

		Mean response of GDP growth	Agr. GDP growth	Non-agr. GDP growth
Oil price	Quarter 0	0.0007	0.0047	0.0005
	Quarter 1	0.0009	0.0052	0.0007
	Quarter 2	0.0020*	0.0149*	0.0018
	Quarter 3	0.0024*	0.0179**	0.0023*
	Quarter 4	0.0026*	0.0177*	0.0025*
	Quarter 5	0.0024*	0.0148*	0.0023*
	Quarter 6	0.0028**	0.0161*	0.0027**
	Quarter 7	0.0029**	0.0153*	0.0029**
	Quarter 8	0.0022*	0.0123	0.0022*
	Quarter 9	0.0024**	0.0131*	0.0024**
	Quarter 10	0.0022**	0.0109	0.0022**
	Quarter 11	0.0019**	0.0097	0.0019**
	Quarter 12	0.0015	0.0066	0.0014
	Quarter 13	0.0016*	0.0090*	0.0017**
	Quarter 14	0.0014*	0.0077	0.0014*
	Quarter 15	0.0014*	0.0074	0.0015*
	Quarter 16	0.0013*	0.0057	0.0013*
	Cumulative effect	0.0327*	0.1890*	0.0321*
Temperature	Quarter 0	0.0022	-0.0003	0.0021
	Quarter 1	-0.0044	-0.0366*	-0.0048
	Quarter 2	-0.0008	-0.0199	-0.0009
	Quarter 3	-0.0006	-0.0185	-0.0007
	Quarter 4	-0.0042	-0.0295	-0.0042
	Quarter 5	-0.0058	-0.0345	-0.0053
	Quarter 6	-0.0066*	-0.0451*	-0.0067*
	Quarter 7	-0.0103**	-0.0591**	-0.0104**

Note: * and ** indicates statistical significance at the 10% level and 5% level, respectively.

Table 6: Mean Response of GDP Growth to Oil Price and Climatic Shocks (Continued)

		GDP growth	Agr. GDP growth	Non-agr. GDP growth
Temperature	Quarter 8	-0.0056	-0.0403	-0.0053
	Quarter 9	-0.0067**	-0.0412*	-0.0069**
	Quarter 10	-0.0049*	-0.0261	-0.0048*
	Quarter 11	-0.0046*	-0.0344*	-0.0047*
	Quarter 12	-0.0028	-0.0137	-0.0029
	Quarter 13	-0.0044*	-0.0295*	-0.0046*
	Quarter 14	-0.0034	-0.0219	-0.0035
	Quarter 15	-0.0038*	-0.0225*	-0.0040*
	Quarter 16	-0.0035*	-0.0181	-0.0036*
	Cumulative effect	-0.0700	-0.4911	-0.0711
Precipitation	Quarter 0	0.0020	0.0109	0.0021
	Quarter 1	0.0012	0.0069	0.0011
	Quarter 2	0.0000	-0.0038	-0.0002
	Quarter 3	-0.0001	0.0001	0.0000
	Quarter 4	-0.0038	-0.0181	-0.0038
	Quarter 5	0.0008	0.0071	0.0010
	Quarter 6	0.0019	0.0168	0.0020
	Quarter 7	-0.0013	0.0040	-0.0013
	Quarter 8	0.0008	0.0099	0.0007
	Quarter 9	0.0009	0.0127	0.0007
	Quarter 10	0.0005	0.0120	0.0006
	Quarter 11	0.0003	0.0037	0.0002
	Quarter 12	0.0005	0.0112	0.0004
	Quarter 13	0.0001	0.0040	0.0000
	Quarter 14	0.0003	0.0055	0.0002
	Quarter 15	0.0003	0.0058	0.0003
	Quarter 16	0.0001	0.0040	0.0002
	Cumulative effect	0.0044	0.0927	0.0040

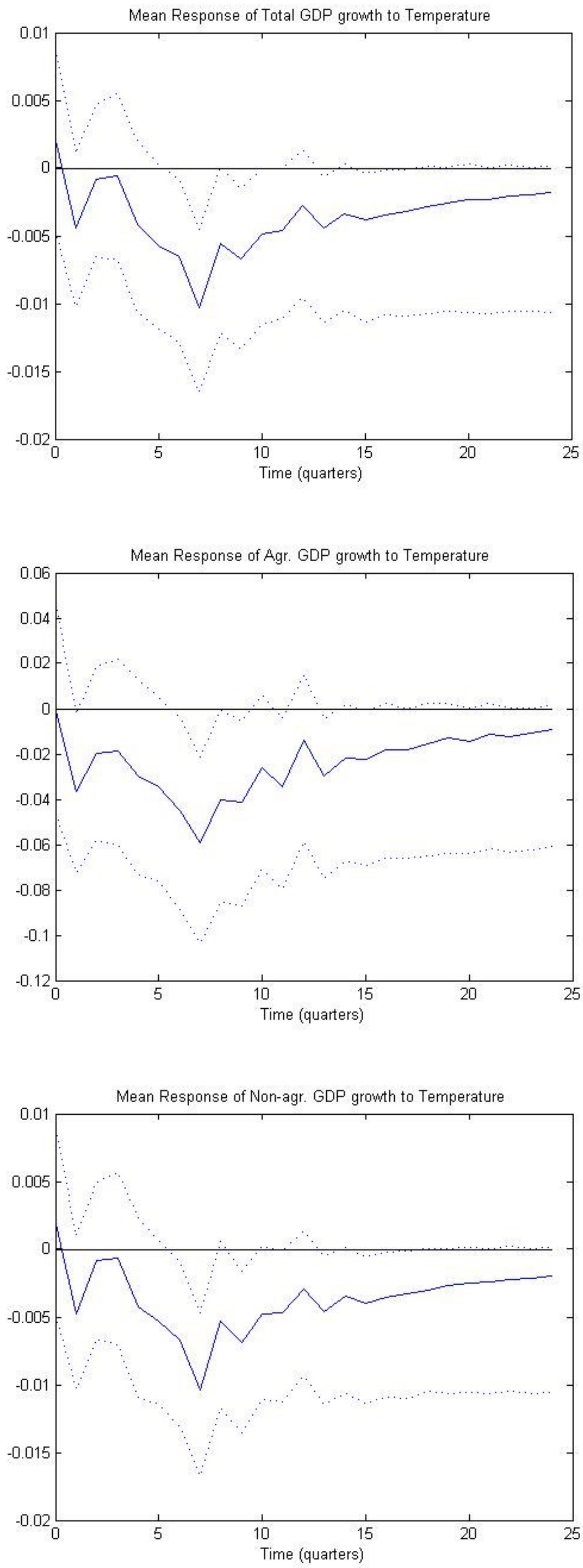

Figure 2: Response of GDP Growth to Temperature Shocks

4.2 Temperature Shocks

Figure 2 presents the responses of the growth rates to temperature shocks. Temperature shocks tend to show negative impacts on economic growth. The shocks tend to introduce similar response patterns and long lasting impacts for total GDP growth as well as both types of sectorial growth. The effect is not significant in the quarter of the shock but becomes significant only for agricultural growth after one quarter, which indicates the sensitivity of agriculture to temperature shocks. It becomes more significant in about one year after the event, signalling the presence of delayed effects. The peaks of the impacts appear after seven quarters from the shock for all the growth rates. The effect is stronger for agricultural growth, with a cumulative effect (absolute value) of 49 pp, compared with 7 pp for aggregated GDP growth and 7 pp for non-agricultural GDP growth (again, indicating that the agricultural sector is more sensitive and vulnerable to temperature changes). In addition, there is no sign of recovery but a build-up of negative responses to the growth rates in time.

It is reported that higher winter temperature is beneficial through lower feed requirements and reduced energy costs (Rotter and van de Geijn 1999) and longer frost-free days and growing season. But warming during summer is stressful for animals (e.g., deaths, low appetite and reduced weight gain) (Adams et al. 1999). Heat also becomes harmful to crops when it passes certain thresholds (Schlenker and Roberts 2009). Higher temperature would increase the number of days with excessive heat and lead to a negative impact on crop yields (Kulshreshtha 2011). Together with these arguments, Wheaton and Kulshreshtha (2010) report trends toward fewer days with extreme low temperature but more days with extreme high temperature in the Prairies. More extremely hot days will be stressful for agricultural production, which may explain why temperature shocks tend to introduce a significant negative impact on Alberta's economic growth.

In addition, warming tends to come with higher probability of extreme weather events, such as droughts and heat spells. Fomby, Ikeda and Loayza (2013), Cuñado and Ferreira (2011) and Hochrainer (2009) report that droughts have an overall negative effect on

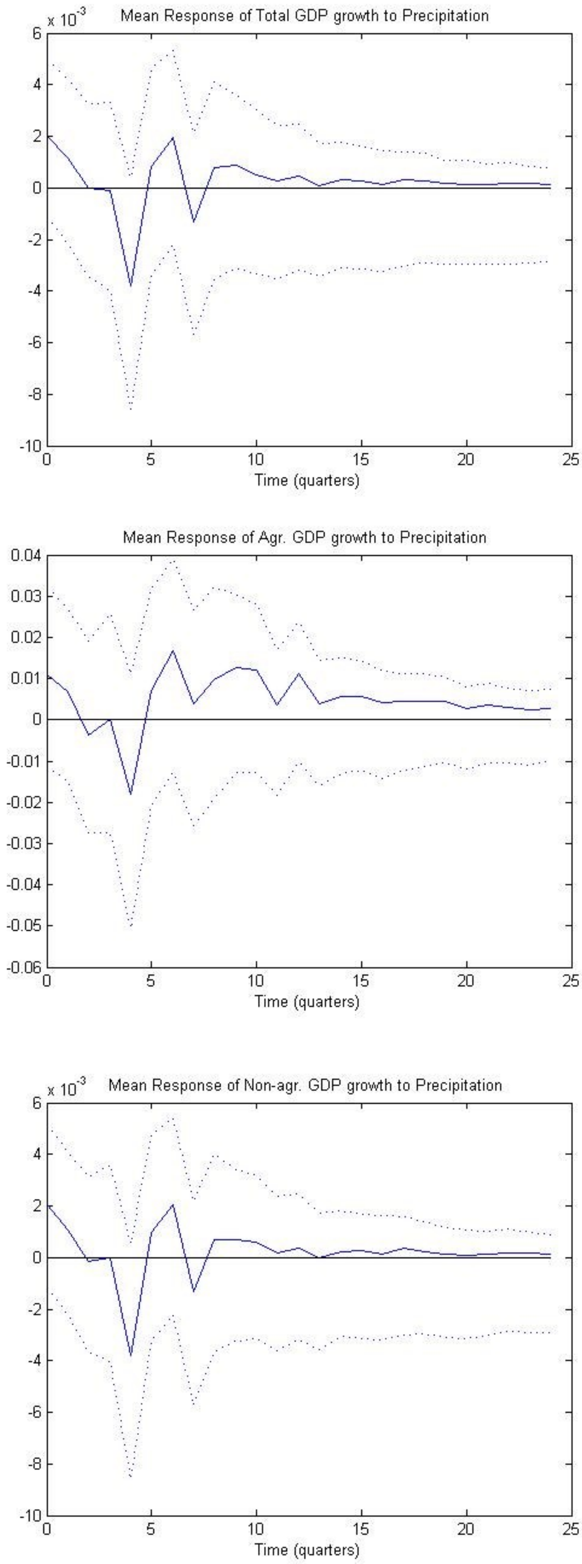

Figure 3: Response of GDP Growth to Precipitation Shocks

economic growth, particularly for agricultural growth. For example, Kulshreshtha and Marleau (2005a; 2005b) report that the 2001 drought lead to a loss of $0.27 billion to crop production and $0.07 billion to the livestock sector in Alberta, and the 2002 drought resulted in $1.3 billion loss to crop production and $0.06 billion loss to the livestock sector in Alberta. Also, increased temperature may also lead to a higher likelihood of water scarcity. Given the fact that Alberta is a semiarid province, water scarcity has been a serious challenge for its agriculture as well as the entire society (Kulshreshtha 2011).

4.3 Precipitation Shocks

Figure 3 depicts the path of economic growth to precipitation shocks. The results are weaker in terms of statistical significance compared to that of temperature shocks. Precipitation shocks tend to induce volatility of growth but an overall positive effect on growth. Specifically, the mean response of growth is positive until the second quarter after the shock (for all three growth rates). The negative impacts only persist for about three periods. Examining the cumulative effects, again, the agricultural sector tends to be more sensitive to precipitation shocks, with a larger cumulative effect (of 9 pp) than total GDP growth and non-agricultural GDP growth. The sensitivity of agriculture to precipitation shocks is also seen by the longer decay rate for agriculture shown in the graph.

Given the climatic nature of aridity for Alberta, we expected increased precipitation would introduce significantly positive impacts on agricultural growth (for instance, increased precipitation leads to more stream flow and more water available for irrigation). However, the non-significant results may be because precipitation shocks could come in different frequency and duration (which offset some of the benefits from more precipitation). For example, heavy rainfall may result in floods. Floods could reduce seeded area; changing the time of seeding and harvesting for crops (Kulshreshtha 2011). Heavy precipitation could also damage infrastructure (e.g., the transportation sector, such as roads and railways). For example, the 2013 Alberta floods are estimated to have resulted in damages of $5 billion (Government of Alberta 2014). However, when considering the impact of floods on GDP

Table 7: Mean Response of GDP Growth to Oil Price and Climatic Shocks (Using Unweighted Climate Variables)

		Mean response of GDP growth	Agr. GDP growth	Non-agr. GDP growth
Oil price	Quarter 0	0.0006	0.0062	0.0005
	Quarter 1	0.0010	0.0071	0.0009
	Quarter 2	0.0018*	0.0125*	0.0017
	Quarter 3	0.0023*	0.0169**	0.0023*
	Quarter 4	0.0024*	0.0162*	0.0023*
	Quarter 5	0.0027**	0.0176**	0.0026**
	Quarter 6	0.0029**	0.0187**	0.0028**
	Quarter 7	0.0029**	0.0178**	0.0029**
	Quarter 8	0.0021**	0.0147**	0.0021*
	Quarter 9	0.0023**	0.0156**	0.0024**
	Quarter 10	0.0019**	0.0119**	0.0019**
	Quarter 11	0.0017**	0.0107**	0.0017**
	Quarter 12	0.0012*	0.0072	0.0012*
	Quarter 13	0.0012*	0.0091**	0.0012*
	Quarter 14	0.0011*	0.0080**	0.0011*
	Quarter 15	0.0010*	0.0065*	0.0010*
	Quarter 16	0.0008*	0.0052	0.0009*
	Cumulative effect	0.0301*	0.2017**	0.0295*
Temperature	Quarter 0	0.0003	-0.0043	0.0001
	Quarter 1	-0.0038	-0.0306	-0.0040
	Quarter 2	-0.0008	-0.0169	-0.0008
	Quarter 3	-0.0049	-0.0361	-0.0048
	Quarter 4	-0.0060	-0.0465	-0.0060
	Quarter 5	-0.0082	-0.0556	-0.0079
	Quarter 6	-0.0114**	-0.0735*	-0.0114*
	Quarter 7	-0.0146**	-0.0898**	-0.0148**

Note: * and ** indicates statistical significance at the 10% level and 5% level, respectively.

Table 7: Mean Response of GDP Growth to Oil Price and Climatic Shocks (Continued)

		GDP growth	Agr. GDP growth	Non-agr. GDP growth
Temperature	Quarter 8	-0.0066	-0.0486	-0.0062
	Quarter 9	-0.0104**	-0.0612*	-0.0106**
	Quarter 10	-0.0069*	-0.0395	-0.0067*
	Quarter 11	-0.0067*	-0.0476*	-0.0067*
	Quarter 12	-0.0038	-0.0192	-0.0037
	Quarter 13	-0.0051*	-0.0393**	-0.0051*
	Quarter 14	-0.0040	-0.0300*	-0.0040
	Quarter 15	-0.0041*	-0.0261*	-0.0043*
	Quarter 16	-0.0031	-0.0213	-0.0032
	Cumulative effect	-0.1000	-0.6859	-0.1001
Precipitation	Quarter 0	-0.0005	0.0015	-0.0004
	Quarter 1	0.0003	0.0029	0.0003
	Quarter 2	-0.0002	-0.0019	-0.0003
	Quarter 3	0.0014	0.0099	0.0017
	Quarter 4	-0.0017	-0.0055	-0.0016
	Quarter 5	-0.0002	0.0059	0.0000
	Quarter 6	0.0026	0.0249	0.0027
	Quarter 7	0.0003	0.0091	0.0001
	Quarter 8	0.0011	0.0123	0.0012
	Quarter 9	0.0010	0.0123	0.0009
	Quarter 10	0.0012	0.0123	0.0013
	Quarter 11	0.0007	0.0055	0.0006
	Quarter 12	0.0006	0.0083	0.0006
	Quarter 13	0.0005	0.0059	0.0005
	Quarter 14	0.0006	0.0069	0.0006
	Quarter 15	0.0004	0.0052	0.0004
	Quarter 16	0.0004	0.0043	0.0004
	Cumulative effect	0.0085	0.1195	0.0088

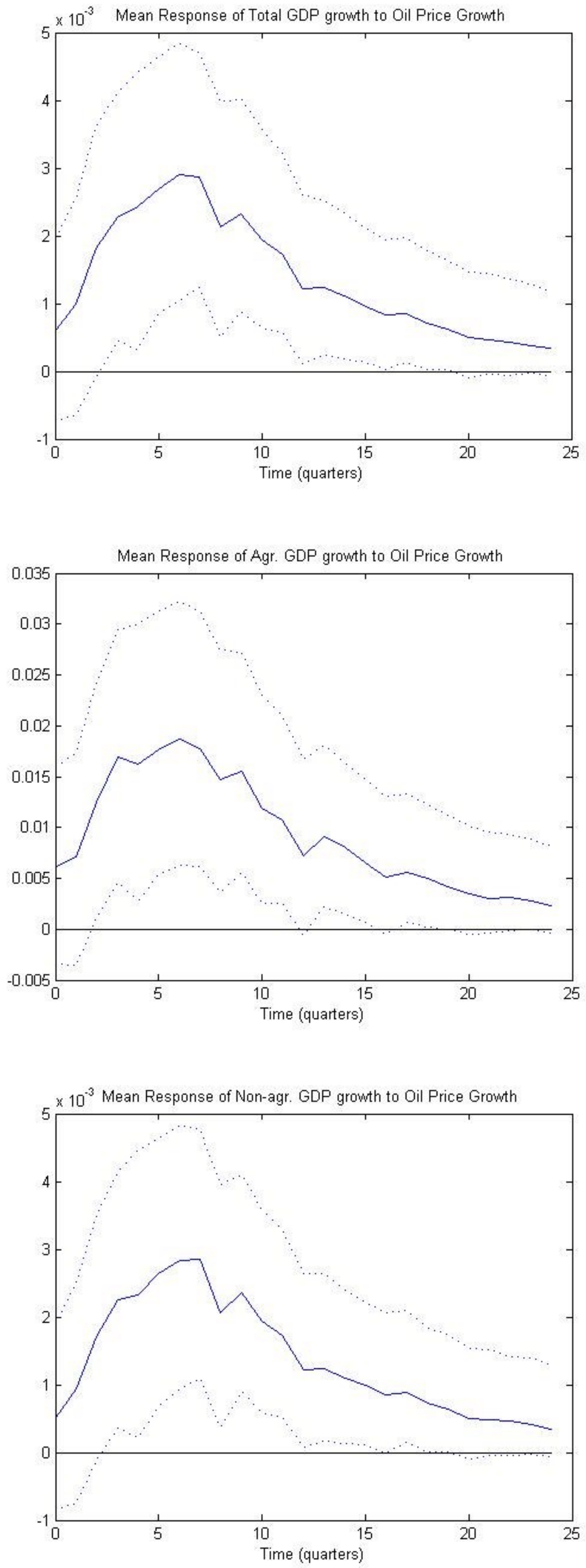

Figure 4: Response of GDP Growth to Oil Price Shocks Using Unweighted Climate Variables

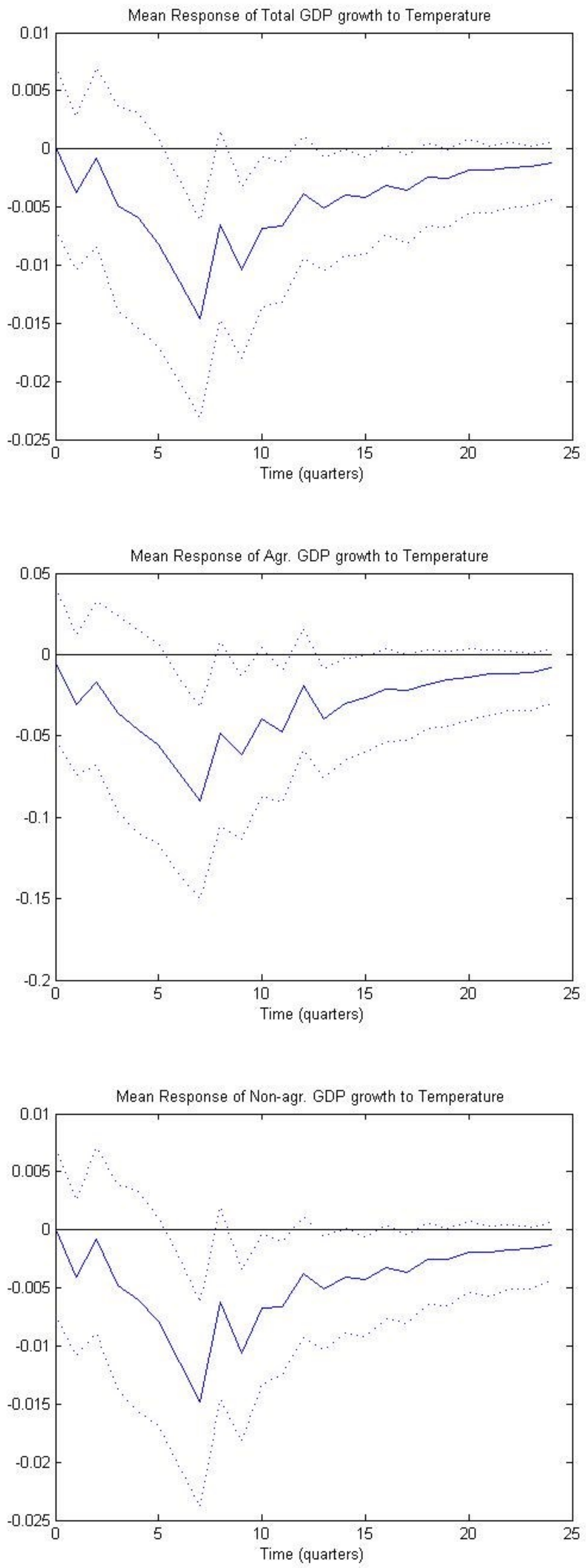

Figure 5: Response of GDP Growth to Temperature Shocks Using Unweighted Climate Variables

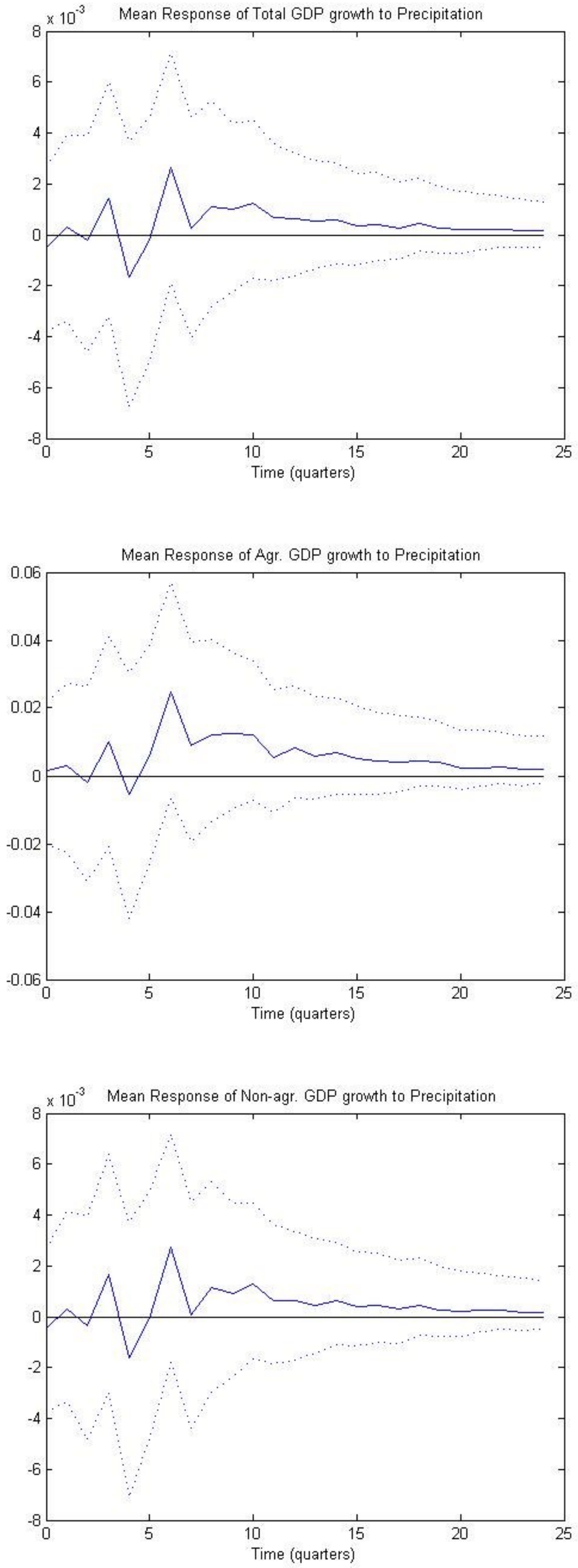

Figure 6: Response of GDP Growth to Precipitation Shocks Using Unweighted Climate Variables

growth, Fomby, Ikeda and Loayza (2013), Cuñado and Ferreira (2011) and Hochrainer and Mechler (2009) find that floods tend to have a positive effect on economic growth after the floods. The authors note that this may be due to potentially beneficial effects on land productivity on the following harvest cycle and it may also result from the importance of transmission mechanisms. For example, abundant water supply boosts electricity generation, which in turn facilitates the overall economic performance through industrial and service expansion (Fomby, Ikeda and Loayza 2013). Reconstruction (for the infrastructure) efforts may also lead to growth rebound. However, it is worth noting again that GDP is simply a measure of economic activity, not social wealth or welfare (Kousky 2012). GDP and welfare impacts may follow different directions due to changes in the economic system (Ochuodho and Lantz 2015; Zhai et al. 2009). Natural disasters will certainly bring about other negative impacts (e.g., deaths, injuries and interruption of public services), which will be harmful to social welfare.

4.4 Unweighted vs. Population-Weighted Climate Variables

The climatic conditions (in terms of temperatures and precipitation) vary considerably across the province. However, as discussed earlier, the majority of Alberta's GDP is generated from the central and southern parts of the province. Using the normal climate variables at a provincial level is not appropriate due to the difference in the distribution of economic activities and climatic conditions across the province. As shown in Figures 4 to 6 and Table 7, the responses of growth due to both climatic shocks tend to be larger when considering the unweighted climate variables relative to the population-weighted climate variables for all three growth rates. For example, the cumulative effect (absolute value) on agricultural growth from temperature shocks using the unweighted climate variables is 19 pp larger than that of using the population-weighted climate variables; the cumulative effect on non-agricultural growth from precipitation shocks using the unweighted climate variables is 0.5 pp larger than that of using the population-weighted climate variables.

Using the population-weighted climate variables is certainly not perfect relative to

Table 8: Mean Response of GDP Growth to Oil Price and Climatic Shocks (With p=q=3 for GDP Growth and Non-agr. GDP Growth)

		Mean response of GDP growth	Agr. GDP growth (p=q=4)	Non-agr. GDP growth
Oil price	Quarter 0	-0.0002	0.0047	-0.0004
	Quarter 1	-0.0003	0.0052	-0.0005
	Quarter 2	0.0010	0.0149*	0.0009
	Quarter 3	0.0011	0.0179**	0.0011
	Quarter 4	0.0013	0.0177*	0.0012
	Quarter 5	0.0008	0.0148*	0.0007
	Quarter 6	0.0011	0.0161*	0.0011
	Quarter 7	0.0015*	0.0153*	0.0015*
	Quarter 8	0.0014*	0.0123	0.0014*
	Quarter 9	0.0009	0.0131*	0.0008
	Quarter 10	0.0010	0.0109	0.0009
	Quarter 11	0.0008	0.0097	0.0008
	Quarter 12	0.0006	0.0066	0.0006
	Quarter 13	0.0006	0.0090*	0.0006
	Quarter 14	0.0007	0.0077	0.0007
	Quarter 15	0.0006	0.0074	0.0006
	Quarter 16	0.0005	0.0057	0.0005
	Cumulative effect	0.0132	0.1890*	0.0123
Temperature	Quarter 0	0.0005	-0.0003	0.0005
	Quarter 1	-0.0046*	-0.0366*	-0.0048*
	Quarter 2	-0.0009	-0.0199	-0.0010
	Quarter 3	-0.0023	-0.0185	-0.0024
	Quarter 4	-0.0055*	-0.0295	-0.0058*
	Quarter 5	-0.0049*	-0.0345	-0.0049*
	Quarter 6	-0.0055*	-0.0451*	-0.0054*
	Quarter 7	-0.0071**	-0.0591**	-0.0072**

Note: * and ** indicates statistical significance at the 10% level and 5% level, respectively.

Table 8: Mean Response of GDP Growth to Oil Price and Climatic Shocks (Continued)

		GDP growth	Agr. GDP growth (p=q=4)	Non-agr. GDP growth
Temperature	Quarter 8	-0.0059**	-0.0403	-0.0058**
	Quarter 9	-0.0035	-0.0412*	-0.0034
	Quarter 10	-0.0034*	-0.0261	-0.0033*
	Quarter 11	-0.0032*	-0.0344*	-0.0032*
	Quarter 12	-0.0029*	-0.0137	-0.0028*
	Quarter 13	-0.0031**	-0.0295*	-0.0031**
	Quarter 14	-0.0028**	-0.0219	-0.0028**
	Quarter 15	-0.0024*	-0.0225*	-0.0024*
	Quarter 16	-0.0021*	-0.0181	-0.0020*
	Cumulative effect	-0.0596	-0.4911	-0.0598
Precipitation	Quarter 0	0.0022	0.0109	0.0023
	Quarter 1	0.0023	0.0069	0.0024
	Quarter 2	0.0005	-0.0038	0.0005
	Quarter 3	0.0010	0.0001	0.0011
	Quarter 4	0.0014	-0.0181	0.0015
	Quarter 5	0.0027	0.0071	0.0029
	Quarter 6	0.0013	0.0168	0.0014
	Quarter 7	0.0016	0.0040	0.0016
	Quarter 8	0.0017	0.0099	0.0018
	Quarter 9	0.0017	0.0127	0.0018
	Quarter 10	0.0012	0.0120	0.0013
	Quarter 11	0.0011	0.0037	0.0011
	Quarter 12	0.0009	0.0112	0.0009
	Quarter 13	0.0009	0.0040	0.0010
	Quarter 14	0.0009	0.0055	0.0010
	Quarter 15	0.0008	0.0058	0.0009
	Quarter 16	0.0007	0.0040	0.0007
	Cumulative effect	0.0230	0.0927	0.0242

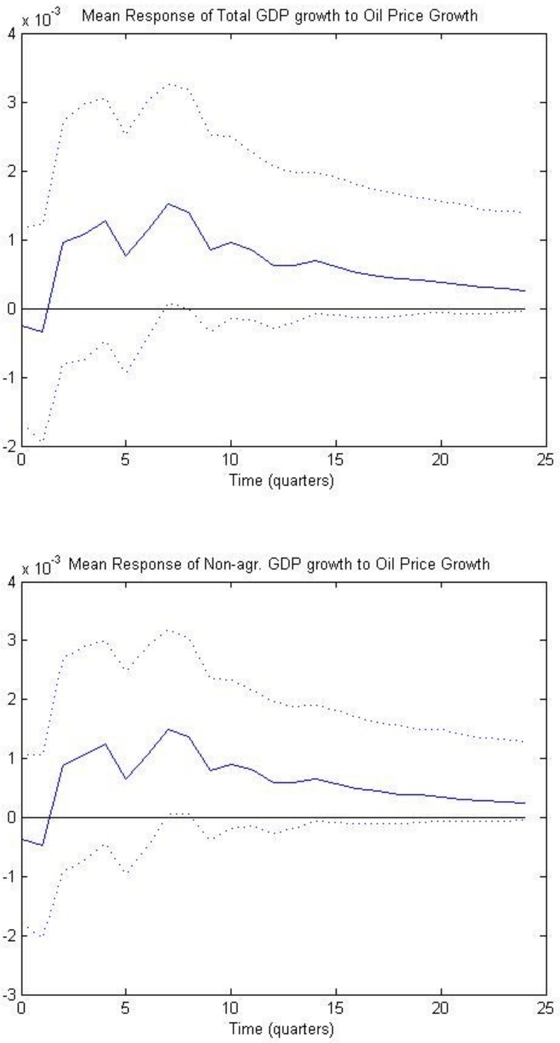

Figure 7: Response of GDP Growth to Oil Price Shocks Using p=q=3

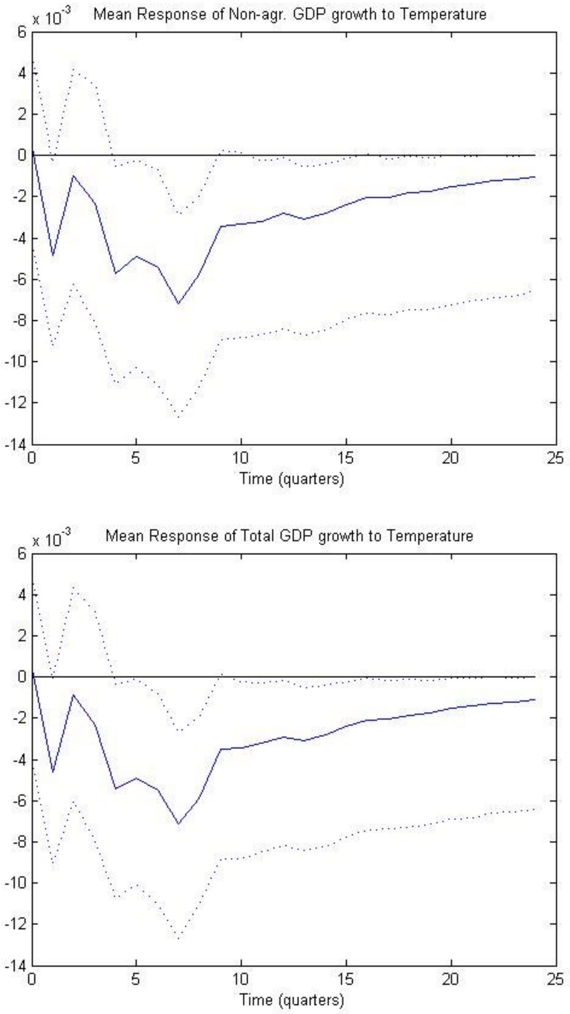

Figure 8: Response of GDP Growth to Temperature Shocks Using p=q=3

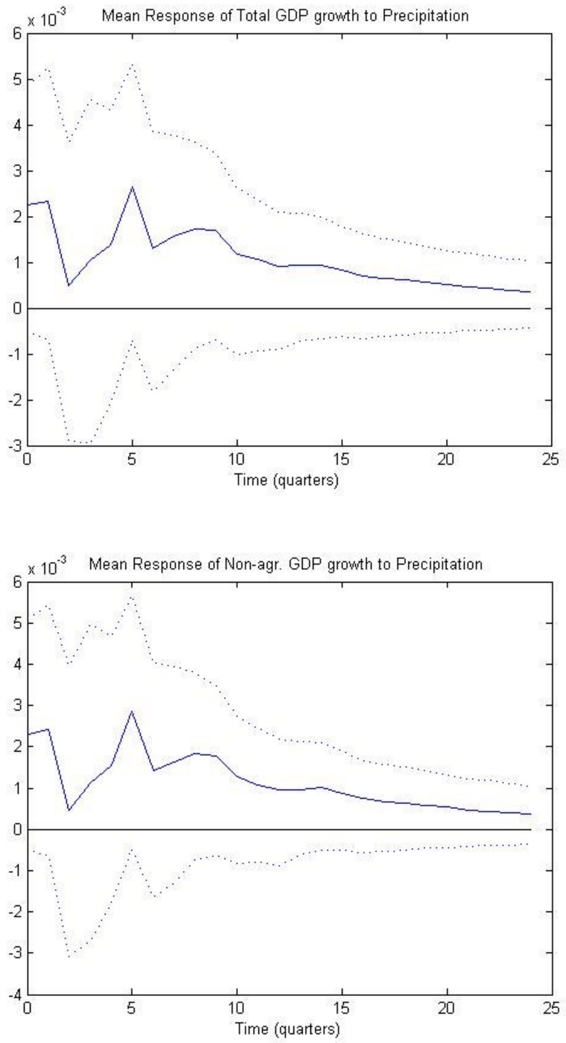

Figure 9: Response of GDP Growth to Precipitation Shocks Using p=q=3

having sub-provincial climate variables, but it is a remedy to mitigate the potential bias given the current limited dataset to investigate economic impacts of climatic shocks.

4.5 Robustness Checks

Lastly, we test the robustness of our models by using the lag length suggested by the AIC.[20] We run models for total GDP growth and non-agricultural GDP growth using p = q= 3. As indicated in Figures 7 to 9 and Table 8. The results are basically similar to those using the preferred lag length of four. The main difference is that with the shorter lag structure, the cumulative response due to precipitation shocks tends to be larger compared to those in the

[20] Since the data are quarterly, the lag structure of p = q= 1 suggested by BIC is considered too restrictive.

models with a lag length of four (but still not statistically significant); the mean responses due to temperature shocks tend to become significant in the earlier quarters while the cumulative response becomes smaller than the results using the prefered lag length. For oil price shocks, the mean responses and cumulative responses are smaller and less significant. In particular, the significant impacts are only shown in quarter 7 and quarter 8 after the shock.

4.6 Simulation of Climate Change on Economic Growth

We estimated the responses of GDP growth due to climatic shocks by isolating temperature and precipitation conditions. The response of GDP growth to temperature-precipitation interacted shock is challenging to estimate within the VARX framework (not studied in this research), although it is plausible that precipitation may partially alleviate negative impacts of extreme high temperatures on economic growth, especially for agricultural production. In this section, we utilize simulation within the VARX model to examine the impacts of temperature-precipitation interactions on GDP growth.

Based on the coefficient estimates of our VARX model, we consider four climate change scenarios. For the purpose of this study as well as due to the limited information on the future values of our variables, we conduct an in-sample analysis for the period from 2000 Q1 to 2007 Q4 rather than an out-of-sample forecast. In Scenario 1, we assume a 30% increase[21] in temperatures for each quarter within the forecast period. In Scenario 2, an assumption of a 30% increase in precipitation is made. Two scenarios (Scenarios 3 and 4) are constructed to consider temperature and precipitation changes at the same time. Scenario 3 is to show the mitigation of precipitation to increased temperatures on GDP growth. We assume both temperatures and precipitation go up by 30% in Scenario 3. For Scenario 4, we assume a 30% increase in temperatures and a 30% decrease in precipitation.

Prior to our simulations, we examine the performance of our VARX model by plotting

[21] The average maximum temperature from 1986 Q1 to 2007 Q4 was about 7°C (see Table 2.1), so 30% increase in temperature is 2°C. This may be an extreme case in the short run. However, the purpose of this section is to examine the temperature-precipitation interactions, not scenario analysis. The average total precipitation during the same period was about 110 mm (see Table 2.1), so 30% increase in precipitation is 33 mm.

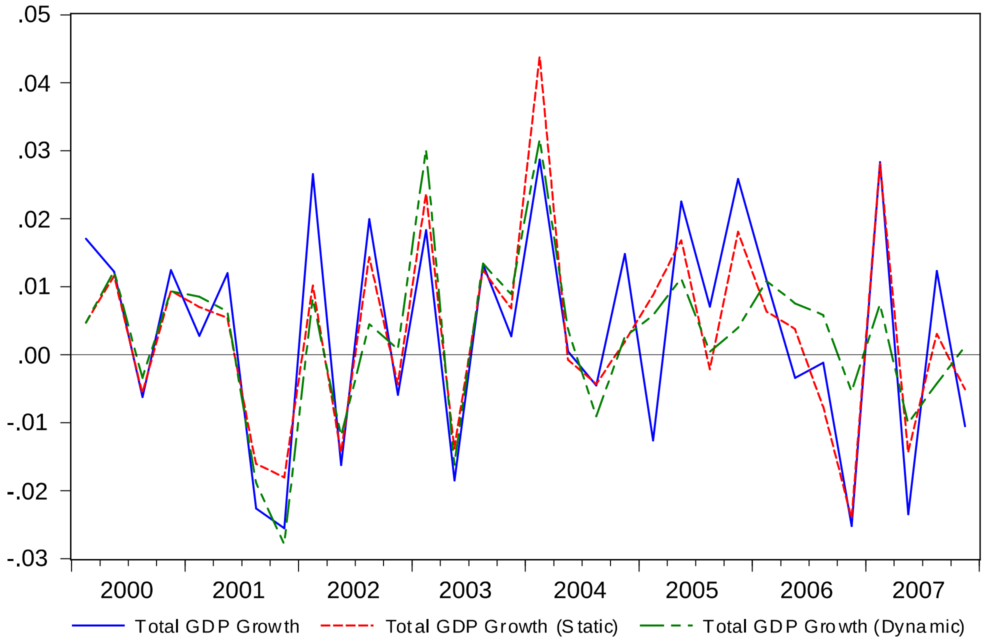

Figure 10: Static and Dynamic Forecasts of Total GDP Growth, 2000 Q1 to 2007 Q4 (In-Sample Forecast)

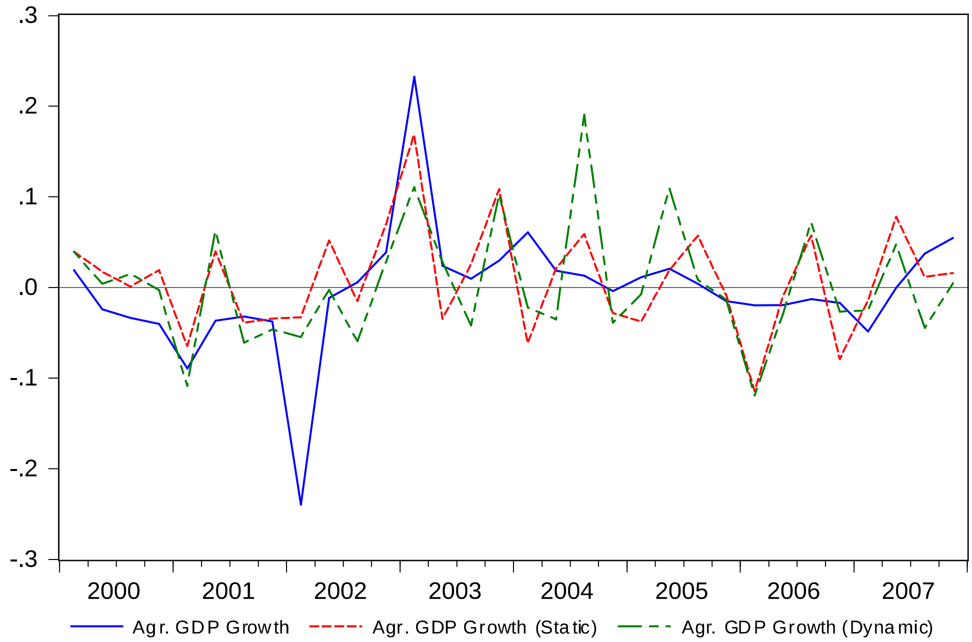

Figure 11: Static and Dynamic Forecasts of Agricultural GDP Growth, 2000 Q1 to 2007 Q4 (In-Sample Forecast)

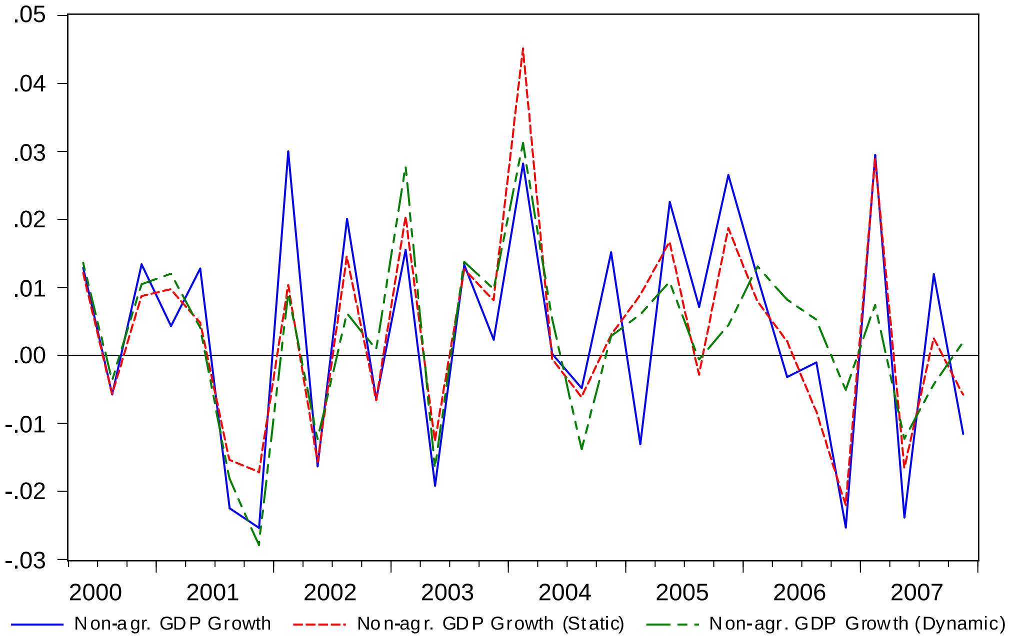

Figure 12: Static and Dynamic Forecasts of Non-agricultural GDP Growth, 2000 Q1 to 2007 Q4 (In-Sample Forecast)

the forecast values against the real values. Figure 10 and Figure 12 show two types of forecasts (i.e., the static and the dynamic forecasts) and the real values for total GDP growth and non-agricultural GDP growth[22]. Both the static and dynamic forecasts are very similar and considered satisfactory in terms of capturing the trends and the magnitude. The static method produces accurate forecasts throughout the whole period, while the dynamic approach yields accurate forecasts in the earlier period (2000 Q2 to 2004 Q2), but seems to underestimate the real values after that. In contrast, our VARX performs relatively less well in forecasting agricultural GDP growth as shown by Figure 11 that illustrates that some obvious deviations between the forecasts and the real values appear. This may be because agriculture GDP accounts for only a small share of total GDP while the economic variables used in the VARX model are economy-wide. As indicated in Figure 11, our forecasts on agricultural GDP growth seem to lean a little too heavily on seasonal fluctuations while the

[22] Since the patterns of total GDP and non-agricultural GDP are very similar, we discuss them together.

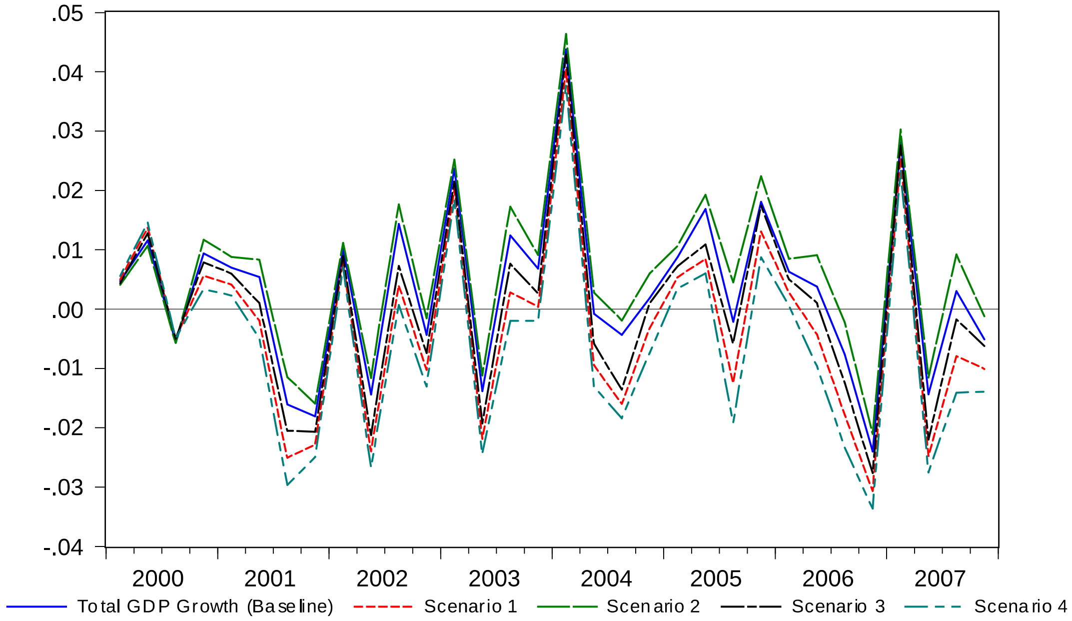

Figure 13: Forecasts of Total GDP Growth under Different Scenarios*, 2000 Q1 to 2007 Q4 (In Sample Forecast)

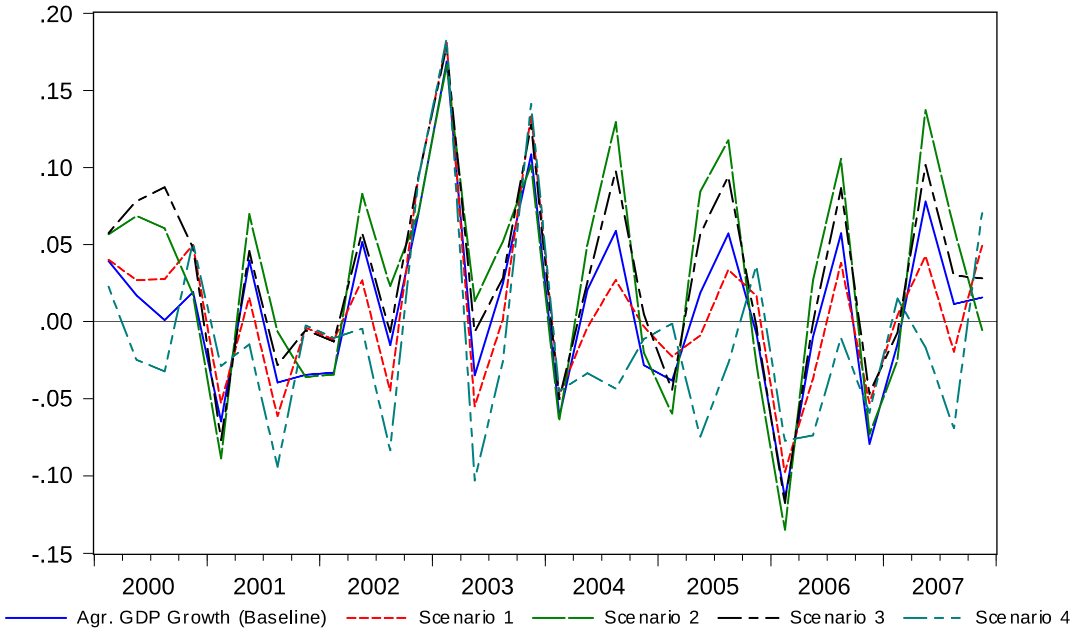

Figure 14: Forecasts of Agricultural GDP Growth under Different Scenarios*, 2000 Q1 to 2007 Q4 (In Sample Forecast)

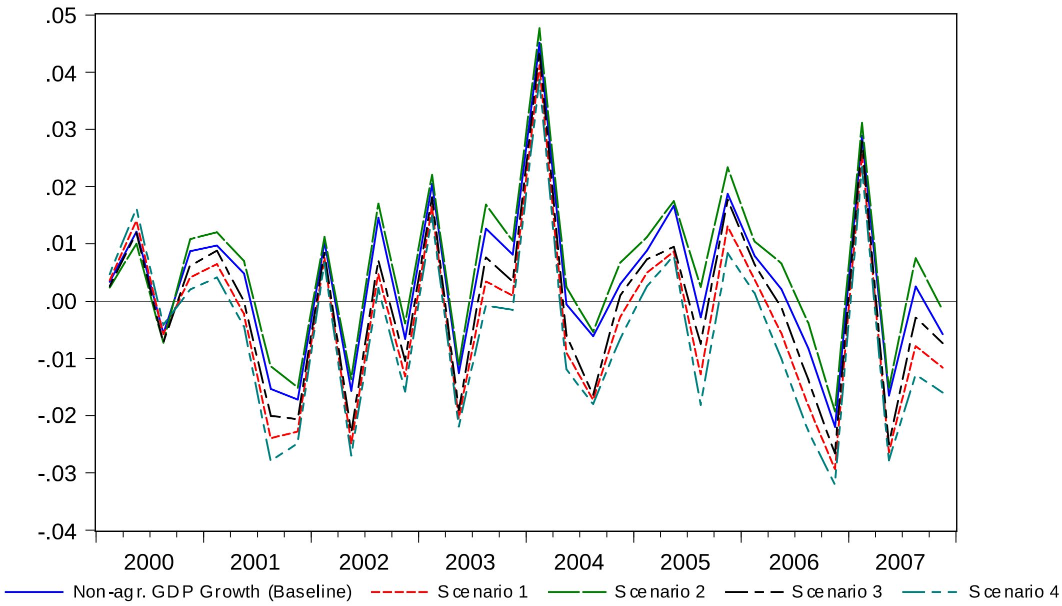

Figure 15: Forecasts of Non-agricultural GDP Growth under Different Scenarios*, 2000 Q1 to 2007 Q4

Note: *The baseline uses the static forecast without any adjustments to the actual variables. In Scenario 1, we assume a 30% increase in temperatures for each quarter within the forecast period. In Scenario 2, we assume a 30% increase in precipitation. In Scenario 3, we assume both temperatures and precipitation go up by 30%. In Scenario 4, we assume a 30% increase in temperatures and a 30% decrease in precipitation.

actual values do not show much seasonal fluctuations especially between 2004 Q2 and 2006 Q3. The static method seems to yield better forecasts compared with the dynamic forecasts for three types of GDP growth. This is not surprising since this is an in-sample forecast; the static method uses the actual values while the dynamic method does not use the actual values but utilizes the forecasted values based on the VARX system. For our purposes, we proceed with our simulations using the static forecasting approach. We depict the simulations of four scenarios against the baseline (i.e., the static forecast without any adjustments to the actual variables) to identify and compare the impacts under the different climate change scenarios. Due to the assumption of linearity embedded in the VARX model, different scenarios tend to shift the baseline upward or downward. As Figures 13 to Figure 15 illustrate, a 30% increase in temperatures (i.e., Scenario 1) tends to lower GDP growth; a 30% increase in precipitation (i.e., Scenario 2) tends to increase all types of GDP growth, and a 30% increase in

Table 9: Forecasts of Total GDP Growth under Different Scenarios, 2000 Q1 to 2007 Q4

Time	Baseline	Scenario 1	Scenario 2	Scenario 3	Scenario 4
2000 Q1	0.005	0.005	0.004	0.004	0.006
2000 Q2	0.012	0.014	0.011	0.013	0.015
2000 Q3	-0.006	-0.005	-0.006	-0.005	-0.005
2000 Q4	0.009	0.006	0.012	0.008	0.003
2001 Q1	0.007	0.004	0.009	0.006	0.002
2001 Q2	0.005	-0.002	0.008	0.001	-0.005
2001 Q3	-0.016	-0.025	-0.012	-0.021	-0.030
2001 Q4	-0.018	-0.023	-0.016	-0.021	-0.025
2002 Q1	0.010	0.008	0.011	0.009	0.007
2002 Q2	-0.014	-0.024	-0.012	-0.021	-0.027
2002 Q3	0.014	0.004	0.018	0.007	0.001
2002 Q4	-0.004	-0.010	-0.002	-0.007	-0.013
2003 Q1	0.024	0.020	0.025	0.022	0.019
2003 Q2	-0.014	-0.022	-0.011	-0.019	-0.025
2003 Q3	0.012	0.003	0.017	0.008	-0.002
2003 Q4	0.007	0.000	0.009	0.003	-0.002
2004 Q1	0.044	0.040	0.046	0.043	0.038
2004 Q2	-0.001	-0.009	0.003	-0.006	-0.013
2004 Q3	-0.004	-0.016	-0.002	-0.014	-0.018
2004 Q4	0.002	-0.003	0.006	0.001	-0.007
2005 Q1	0.009	0.005	0.011	0.007	0.003
2005 Q2	0.017	0.008	0.019	0.011	0.006
2005 Q3	-0.002	-0.012	0.005	-0.006	-0.019
2005 Q4	0.018	0.013	0.022	0.017	0.009
2006 Q1	0.006	0.003	0.008	0.005	0.001
2006 Q2	0.004	-0.004	0.009	0.001	-0.010
2006 Q3	-0.008	-0.018	-0.002	-0.012	-0.023
2006 Q4	-0.024	-0.031	-0.021	-0.028	-0.034
2007 Q1	0.028	0.025	0.030	0.028	0.023
2007 Q2	-0.014	-0.025	-0.012	-0.022	-0.028
2007 Q3	0.003	-0.008	0.009	-0.002	-0.014
2007 Q4	-0.005	-0.010	-0.001	-0.006	-0.014

Note: These figures are produced by a static forecast based on the VARX model (see Equation 2). The baseline uses the static forecast without any adjustments to the actual variables. In Scenario 1, we assume a 30% increase in temperatures for each quarter within the forecast period. In Scenario 2, we assume a 30% increase in precipitation. In Scenario 3, we assume both temperatures and precipitation go up by 30%. In Scenario 4, we assume a 30% increase in temperatures and a 30% decrease in precipitation.

Table 10: Forecasts of Agricultural GDP Growth under Different Scenarios, 2000 Q1 to 2007 Q4

Time	Baseline	Scenario 1	Scenario 2	Scenario 3	Scenario 4
2000 Q1	0.039	0.04	0.057	0.058	0.023
2000 Q2	0.017	0.027	0.069	0.078	-0.025
2000 Q3	0.001	0.028	0.061	0.087	-0.032
2000 Q4	0.019	0.05	0.018	0.048	0.051
2001 Q1	-0.064	-0.053	-0.089	-0.077	-0.029
2001 Q2	0.04	0.016	0.070	0.046	-0.015
2001 Q3	-0.039	-0.061	-0.006	-0.028	-0.094
2001 Q4	-0.034	-0.004	-0.036	-0.005	-0.002
2002 Q1	-0.033	-0.012	-0.034	-0.013	-0.01
2002 Q2	0.052	0.027	0.083	0.058	-0.005
2002 Q3	-0.015	-0.045	0.023	-0.006	-0.083
2002 Q4	0.07	0.093	0.070	0.093	0.092
2003 Q1	0.169	0.181	0.166	0.179	0.183
2003 Q2	-0.035	-0.055	0.013	-0.007	-0.103
2003 Q3	0.025	0.001	0.052	0.028	-0.026
2003 Q4	0.108	0.134	0.102	0.128	0.141
2004 Q1	-0.062	-0.047	-0.064	-0.050	-0.045
2004 Q2	0.021	-0.004	0.050	0.026	-0.033
2004 Q3	0.059	0.027	0.130	0.098	-0.044
2004 Q4	-0.028	-0.003	-0.020	0.005	-0.011
2005 Q1	-0.038	-0.023	-0.059	-0.044	-0.001
2005 Q2	0.019	-0.009	0.084	0.057	-0.074
2005 Q3	0.057	0.034	0.118	0.094	-0.027
2005 Q4	-0.008	0.017	-0.028	-0.003	0.036
2006 Q1	-0.115	-0.097	-0.135	-0.118	-0.077
2006 Q2	-0.01	-0.037	0.027	0.000	-0.074
2006 Q3	0.057	0.038	0.106	0.087	-0.01
2006 Q4	-0.079	-0.053	-0.073	-0.047	-0.059
2007 Q1	-0.014	0.004	-0.025	-0.007	0.015
2007 Q2	0.078	0.043	0.137	0.102	-0.017
2007 Q3	0.011	-0.019	0.061	0.030	-0.069
2007 Q4	0.016	0.049	-0.005	0.028	0.07

Note: These figures are produced by a static forecast based on the VARX model (see Equation 2). The baseline uses the static forecast without any adjustments to the actual variables. In Scenario 1, we assume a 30% increase in temperatures for each quarter within the forecast period. In Scenario 2, we assume a 30% increase in precipitation. In Scenario 3, we assume both temperatures and precipitation go up by 30%. In Scenario 4, we assume a 30% increase in temperatures and a 30% decrease in precipitation.

Table 11: Forecasts of Non-agricultural GDP Growth under Different Scenarios, 2000 Q1 to 2007 Q4

Time	Baseline	Scenario 1	Scenario 2	Scenario 3	Scenario 4
2000 Q1	0.003	0.004	0.002	0.003	0.005
2000 Q2	0.012	0.014	0.010	0.012	0.016
2000 Q3	-0.006	-0.006	-0.007	-0.007	-0.004
2000 Q4	0.009	0.004	0.011	0.006	0.002
2001 Q1	0.010	0.006	0.012	0.009	0.004
2001 Q2	0.005	-0.002	0.007	0.000	-0.004
2001 Q3	-0.015	-0.024	-0.011	-0.020	-0.028
2001 Q4	-0.017	-0.023	-0.015	-0.021	-0.025
2002 Q1	0.010	0.008	0.011	0.008	0.007
2002 Q2	-0.016	-0.025	-0.014	-0.023	-0.027
2002 Q3	0.015	0.005	0.017	0.007	0.002
2002 Q4	-0.007	-0.013	-0.004	-0.010	-0.016
2003 Q1	0.020	0.017	0.022	0.018	0.015
2003 Q2	-0.013	-0.020	-0.011	-0.019	-0.022
2003 Q3	0.013	0.003	0.017	0.008	-0.001
2003 Q4	0.008	0.001	0.011	0.003	-0.002
2004 Q1	0.045	0.041	0.048	0.044	0.039
2004 Q2	-0.001	-0.009	0.002	-0.006	-0.012
2004 Q3	-0.006	-0.017	-0.005	-0.016	-0.018
2004 Q4	0.003	-0.003	0.007	0.001	-0.007
2005 Q1	0.009	0.005	0.011	0.007	0.003
2005 Q2	0.017	0.009	0.017	0.009	0.008
2005 Q3	-0.003	-0.013	0.003	-0.007	-0.018
2005 Q4	0.019	0.013	0.023	0.018	0.008
2006 Q1	0.008	0.004	0.010	0.006	0.001
2006 Q2	0.002	-0.006	0.007	-0.001	-0.010
2006 Q3	-0.008	-0.018	-0.004	-0.014	-0.023
2006 Q4	-0.022	-0.029	-0.019	-0.027	-0.032
2007 Q1	0.029	0.026	0.031	0.028	0.023
2007 Q2	-0.017	-0.026	-0.015	-0.025	-0.028
2007 Q3	0.003	-0.008	0.008	-0.003	-0.013
2007 Q4	-0.006	-0.012	-0.001	-0.007	-0.016

Note: These figures are produced by a static forecast based on the VARX model (see Equation 2). The baseline uses the static forecast without any adjustments to the actual variables. In Scenario 1, we assume a 30% increase in temperatures for each quarter within the forecast period. In Scenario 2, we assume a 30% increase in precipitation. In Scenario 3, we assume both temperatures and precipitation go up by 30%. In Scenario 4, we assume a 30% increase in temperatures and a 30% decrease in precipitation temperature but a 30% decreases in precipitation (i.e., Scenario 4) tends to exacerbate the negative impact on economic growth compared with Scenario 1. The growth rate curves of Scenario 3 (i.e., 30% increases on both temperatures and precipitation) lie above the curves of Scenario 1 for all GDP growth. This is as expected since increased precipitation tends to mitigate the negative impacts on GDP growth from increased temperatures. In addition, the mitigation effect of increased precipitation on increased temperatures varies for different types of GDP growth. Scenario 3 tends to yield higher growth rates compared to the baseline for agricultural GDP growth, but smaller growth rates compared to the baseline for both total GDP and non-agricultural GDP growth. Tables 9 to 11 summarize the details of the magnitude of the impacts for each GDP growth under the different scenarios for each quarter. We further calculate[23] the average size of the economic impact over the entire forecast period under each scenario compared with the baseline by the type of GDP growth. For total GDP growth, Scenario 1 leads to an average reduction of 0.6% in the growth rate; Scenario 2 causes a 0.3% increase, Scenario 3 results in a 0.3% decrease and Scenario 4 leads to a 0.9% decrease. Four scenarios tend to have similar average impacts on non-agricultural GDP growth as on total GDP growth. Specifically, Scenario 1 results in an average decrease of 0.6%; Scenario 2 causes a 0.2% increase; Scenarios 3 and 4 lead to reductions of 0.4% and 0.9%, respectively. For agricultural GDP, Scenarios 1 to 3 tend to generate increased rates of agricultural GDP (0.01%, 2% and 2%, respectively) while Scenario 4 results in a negative rate of 2%. However, a closer examination reveals that the scenarios, especially Scenarios 1, 2 and 4, tend to have different impacts on the second and third quarters (i.e., growing season) versus the first quarter and fourth quarters (i.e., non-growing season) for agricultural GDP growth (but not for total GDP and non-agricultural GDP growth). Scenario 1 tends to lead to an average reduction of 2% on agricultural GDP growth when only considering the second and third quarters while an average increased rate of 2% when only considering the first and fourth quarters. Scenario 2 results in an average increased rate of 4.6% for the second quarter and third quarters and a 0.6% decrease for the first and the fourth quarters. Scenario 3 causes

[23] See details in Tables 19 to 21 in Appendix C.

a 2.6% increase for the growing season and a 1.4% increase for the non-growing season. Scenario 4 causes a 6.7% reduction for the second and third quarters while a 2.7% increase for the first and fourth quarters.

Overall, our simulation results are consistent with our previous findings of the responses of economic growth to the temperature and precipitation shocks. That is increased temperatures tend to decrease GDP growth, while increase precipitation tends to increase GDP growth. The agricultural sector tends to be more sensitive and vulnerable to climate change. In addition, our simulation results suggest that increased precipitation partially alleviates negative impacts from increased extreme high temperatures.

5. Concluding Remarks

This study examines the responses of economic growth to temperature and precipitation shocks. We analyze the impacts due to climatic shocks on total GDP growth, agricultural GDP growth and non-agricultural GDP growth. A VARX model is used to shed light on the relationship between climate change and economic growth for Alberta. Population-weighted climate variables are used to account for the difference in the distributions of economic activities and climatic conditions across the province. An in-sample forecast is further used to simulate the mutual effects of changed temperatures and precipitation on GDP growth.

We find that temperature shocks tend to have significant and negative impacts on three forms of GDP growth (up to 16 quarters after temperature shocks for total GDP and non-agricultural GDP growth while 15 quarters for agricultural GDP growth). In contrast to temperature shocks, precipitation shocks tend to result in overall positive impacts on GDP growth (but are not significant). Both shocks tend to produce impacts on economic growth with a lag. As expected, both climatic shocks tend to induce stronger effects on agricultural growth than on total GDP growth and non-agricultural growth. For example, temperature shocks produce a cumulative effect of 49 pp for agricultural growth while 7 pp for aggregated GDP growth and 7 pp for non-agricultural GDP growth. Also, the shocks tend to have longer lasting effects on agricultural growth than on total GDP growth and non-agricultural growth.

We further constructed four scenarios of climate change to conduct in-sample simulations of the economic impacts. Overall, the results of the simulations are consistent with our findings of the responses of economic growth to the temperature and precipitation shocks. For example, a 30% increase in temperatures tend to lower GDP growth, while a 30% increase in precipitation tend to increase GDP growth. When considering temperature and precipitation changes together, increased precipitation tends to partially alleviate negative impacts on economic growth due to increased extreme high temperatures, while decreased precipitation tends to exacerbate on such negative effects. In addition, agriculture GDP growth tends to respond differently to the different climate change scenarios seasonally in contrast with total GDP growth and non-agricultural GDP growth. For example, a 30% increase in temperatures tend to result in an average reduction of 2% on agricultural GDP growth when only considering the second and third quarters (i.e., growing season) while an average increased rate of 2% when only considering the first and fourth quarters (i.e., non-growing season). This seasonal pattern is not seen for total GDP growth and non-agricultural GDP growth.

Climate change (in terms of temperature and precipitation shocks) would induce both positive and negative impacts on the economy and human society. Considering the results together, we conclude that future climate change is more likely to induce net negative impacts on Alberta's economy. Our results are not quite comparable to the existing Canadian literature. This is because 1) this is to the best of our knowledge the first study exploring the impacts of climatic shocks on GDP growth (others investigate such impacts on GDP levels[24]) using a time series model—the VARX model—based on statistical regularities rather than a structured economic model; 2) we investigate such impacts on the provincial economy as a whole; 3) the VARX model can capture the simultaneous impacts of climate change in various sectors, while other approaches might not and 4) when calculating the response of GDP growth, we introduce climate shocks from the VARX system rather than under some future climate change projections. However, the overall direction of GDP impacts of climate change found in this paper are similar to several previous studies (e.g., Ochuodho and Lantz 2015; NRTEE 2011; Zhai et al. 2009) that warming tends to have negative impacts on Alberta's economy.

Climate change will affect various sectors simultaneously in Alberta. Agriculture is the most sensitive sector to climate change. Losses or gains in agriculture will be passed on to other sectors, intuitively, such as the trade and service sectors (Arthur and Freshwater 1986). On the other hand, climate change is likely to have various effects on commodity markets

[24] Traditional IAMs assume climate change only affects the level of GDP not its growth rate. The distinction between the level effects and the growth effects is that the former is transitory, while the latter is persistent and carried into the future (Moore and Diaz 2015). GDP levels can still increase with negative climatic impacts on the growth rate (i.e., reduced growth rate) as long as the growth rate is still positive.

across different parts of the world (i.e., external markets for Alberta), both in supply and demand. It is possible that the responsive path is partially due to changes in international markets through climatic shocks. For example, if international competitors of Canada (such as Australia, the USA and the European Union in cereal and grain exports) have net gains in their agricultural sectors, this in turn will pose threats to Canadian agriculture (as indirect impacts). However, this aspect is more complex and uncertain. We leave it for future investigation.

On the other hand, GDP is simply a measure of economic activity, not social welfare. Climate change could also affect non-market services (e.g., human health and ecosystem services) and therefore social welfare. Climate change is likely to cause increased negative health issues to human beings. For example, high temperatures together with altered air moisture and quality increase heat stroke risk and respiratory illness (e.g., asthma) (NRTEE 2011). Increased natural disasters may result in more injuries, deaths and evacuations for humans. In contrast, a reduction in extreme cold days could decrease illness and deaths in winter. For ecosystems in Canada, there are 15 distinct land ecozones and five marine-based ones. Ecosystems provide food sources, tourism, recreation and regulation in the global climate. Changing climate is altering the quality and health of ecosystems in Canada (NRTEE 2011). Non-market services are an important part of climate change. It is also of paramount importance to analyze the potential impacts of climate change from the perspective of social welfare.

Economists have stated that inaction to climate change is not a wise option. Adaptation to climate change is useful to mitigate the negative impacts and lower the costs of climate impacts (NRTEE 2011; Ochuodho and Lantz 2015). Our knowledge of the potential consequences of climate change and possible cost-effective adaptation strategies is still limited. Future research should continue to explore these knowledge gaps. More cooperation among scientists, decision makers, public and private stakeholders at multiple (e.g., the federal and regional) levels is needed.

6. Limitations and Possible Extensions

Firstly, due to data availability, we are not able to conduct an analysis at a smaller scale (i.e., sub provincial level) but at the provincial level. Climatic conditions vary across the province; using aggregated data may mask some of the economic impacts due to climate change, especially for the agricultural sector. Secondly, the VARX model is linear and coefficients are assumed to be constant over time. However, the relationship between climate change and its impacts on economic growth may not be linear. The relationship may depend on the development level of the economy and the degree of climate change at different points in time. In addition, we assume a constant variance (homoscedasticity) for all the variables. Potential autoregressive conditional heteroscedastic (ARCH) effects are not investigated in this study. Thirdly, we isolated temperature and precipitation shocks when examining the responses of economic impacts to climate shocks. However, variations in temperatures and precipitation tend to be correlated and may come together to affect the economic growth. Precipitation may partially mitigate negative impacts from extreme high temperatures especially for agricultural production. The responses of GDP growth due to temperature-precipitation interactions are beyond the scope of this study. Fourthly, future research may also consider other climate variables, such as the value of temperature/precipitation deviations from the mean and the number of days with maximum temperature over certain threshold. Lastly, the VARX model is not able to analyze social welfare impacts of climate change. GDP is simply a measure of economic activity, not social welfare. Climate change could also affect non-market services and therefore social welfare. While since the model is promising at forecasting, one useful extension is to use the VARX model to predict future economic growth rates using the projections on the economic variables and climate variables to conduct an analysis under different possible scenarios.

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Appendix A

Table 12: VARX Model Estimates (Total GDP Growth)

	Trade	GDP	Unemployment	Fixed Capital	Migration
Trade (-1)	-0.613646	0.029447	0.256276	0.148329	69648.35
	(0.10714)	(0.04591)	(0.17603)	(0.13896)	(40007)
Trade (-2)	-0.624501	0.048291	0.124391	0.195996	-46286.03
	(0.10989)	(0.04709)	(0.18055)	(0.14253)	(41033)
Trade (-3)	-0.596920	-0.031215	0.226008	0.218129	36350.24
	(0.09925)	(0.04253)	(0.16306)	(0.12872)	(37058)
Trade (-4)	-0.376698	0.052303	0.489947	0.227146	-10723.95
	(0.10302)	(0.04414)	(0.16925)	(0.13361)	(38465)
GDP (-1)	-0.165196	-0.130138	0.309010	1.254939	229354.9
	(0.27227)	(0.11667)	(0.44732)	(0.35313)	(101663)
GDP (-2)	0.047403	-0.057925	0.470135	0.255805	47723.26
	(0.24613)	(0.10547)	(0.40438)	(0.31922)	(91902)
GDP (-3)	0.058826	-0.525617	0.651325	0.080503	-62719.41
	(0.23662)	(0.10139)	(0.38876)	(0.30690)	(88354)
GDP (-4)	-0.069518	-0.205194	0.520514	0.253830	86160.67
	(0.25989)	(0.11136)	(0.42699)	(0.33707)	(97041)
Unemployment (-1)	-0.047872	-0.029301	-0.279469	-0.061604	-11069.59
	(0.06737)	(0.02887)	(0.11069)	(0.08738)	(25156)
Unemployment (-2)	-0.160044	-0.005716	-0.168294	-0.091003	-72058.08
	(0.07188)	(0.03080)	(0.11810)	(0.09323)	(26841)
Unemployment (-3)	-0.119382	-0.059675	0.188341	-0.206332	-3790.962
	(0.06590)	(0.02824)	(0.10827)	(0.08547)	(24606)
Unemployment (-4)	0.084960	-0.046690	0.018105	0.025709	-55458.83
	(0.06536)	(0.02801)	(0.10738)	(0.08477)	(24403)

Fixed Capital (-1)	-0.133510	0.045583	-0.095852	-0.003240	3471.919
	(0.09056)	(0.03881)	(0.14879)	(0.11746)	(33816)
Fixed Capital (-2)	-0.028433	0.095356	-0.375599	0.144626	24395.73
	(0.06476)	(0.02775)	(0.10641)	(0.08400)	(24184)
Fixed Capital (-3)	-0.140930	0.028220	-0.008259	-0.466138	24438.83
	(0.07290)	(0.03124)	(0.11978)	(0.09455)	(27221)
Fixed Capital (-4)	-0.288266	0.071033	-0.075564	-0.121467	4674.457
	(0.08150)	(0.03493)	(0.13391)	(0.10571)	(30433)
Migration (-1)	1.56e-07	-3.53e-07	-4.03e-07	-2.00e-07	0.495924
	(2.86e-07)	(1.22e-07)	(4.69e-07)	(3.71e-07)	(0.10669)
Migration (-2)	-5.01e-07	4.56e-07	1.13e-06	6.82e-07	-0.057968
	(2.97e-07)	(1.27e-07)	(4.88e-07)	(3.85e-07)	(0.11096)
Migration (-3)	5.50e-07	-1.67e-07	1.67e-07	-5.01e-07	0.331603
	(2.77e-07)	(1.19e-07)	(4.54e-07)	(3.59e-07)	(0.10328)
Migration (-4)	-3.20e-08	5.61e-09	-5.68e-07	2.36e-08	0.108216
	(2.58e-07)	(1.11e-07)	(4.24e-07)	(3.35e-07)	(0.09643)
C	0.002852	0.021346	-0.070124	-0.016796	5158.132
	(0.02842)	(0.01218)	(0.04669)	(0.03686)	(10611)
Oil Price	-0.038011	0.020885	-0.021580	-0.005772	6265.700
	(0.02746)	(0.01177)	(0.04512)	(0.03352)	(10254)
Oil Price (-1)	-0.104022	0.014028	0.023021	-0.001166	2696.968
	(0.02605)	(0.01116)	(0.04251)	(0.03379)	(9728)
Oil Price (-2)	-0.065188	-0.003130	-0.080710	-0.048277	14680.62
	(0.02586)	(0.01108)	(0.04249)	(0.03354)	(9657)
Oil Price (-3)	-0.023086	0.013300	-0.071871	0.078602	12424.58
	(0.02781)	(0.01192)	(0.04569)	(0.03607)	(10384)
Oil Price (-4)	-0.042680	0.023993	0.038427	0.001482	493.1992
	(0.02845)	(0.01219)	(0.04674)	(0.03690)	(10623)

World GDP	-13.31009	13.52493	-65.82561	21.60931	-2956393.
	(8.3733)	(3.5880)	(13.7571)	(10.8066)	(3126563)
World GDP (-1)	41.83694	-38.69470	133.2850	-49.08131	5884983.
	(19.0292)	(8.1541)	(31.2643)	(24.6806)	(7105425)
World GDP (-2)	-21.38683	39.33638	-93.96051	39.66165	-6130323.
	(24.4109)	(10.4603)	(40.1063)	(31.6606)	(9114934)
World GDP (-3)	-7.565734	-11.82215	-20.28654	-19.18840	1033269.
	(22.7312)	(9.7405)	(37.3465)	(29.4821)	(8487730)
World GDP (-4)	4.425206	-4.928907	36.88847	6.922033	1398412.
	(10.2545)	(4.3941)	(16.8478)	(13.3000)	(3828998)
Temperature	-7.09e-05	7.36e-05	0.000249	0.000833	36.41405
	(0.00023)	(0.00010)	(0.00038)	(0.00030)	(86.7781)
Temperature (-1)	7.79e-05	-9.10e-05	-9.80e-05	-0.000577	-102.4871
	(0.00015)	(0.00007)	(0.00025)	(0.00020)	(56.7485)
Temperature (-2)	-6.94e-05	1.87e-05	0.000518	0.000416	35.26426
	(0.00016)	(0.00007)	(0.00026)	(0.00020)	(59.1559)
Temperature (-3)	-0.000128	-7.80e-05	0.000462	-0.000715	-62.48181
	(0.00016)	(0.00007)	(0.00025)	(0.00020)	(57.7458)
Temperature (-4)	0.000377	-0.000189	-0.000241	-0.000284	42.39575
	(0.00024)	(0.00011)	(0.00041)	(0.00032)	(93.1941)
Precipitation	-1.35e-05	-4.47e-06	6.18e-05	3.16e-05	4.623682
	(0.00001)	(6.28e-06)	(0.00002)	(0.00002)	(5.4758)
Precipitation (-1)	-3.08e-05	5.46e-06	5.09e-05	-1.47e-05	2.845268
	(0.00001)	(5.61e-06)	(0.00002)	(0.00002)	(4.8895)
Precipitation (-2)	2.16e-05	-1.37e-07	-1.48e-05	5.40e-05	3.663855
	(0.00001)	(5.54e-06)	(0.00002)	(0.00002)	(4.8293)
Precipitation (-3)	1.05e-05	1.35e-06	-4.30e-05	3.77e-06	-4.551505
	(0.00001)	(5.70e-06)	(0.00002)	(0.00002)	(4.9701)

Precipitation (-4)	-1.16e-06	9.12e-06	-2.70e-05	-2.12e-05	-7.657239
	(0.00002)	(7.51e-06)	(0.00003)	(0.00003)	(6.6450)
R-squared	0.680121	0.709824	0.673629	0.658619	0.854925
S.E. equation	0.028104	0.012043	0.046174	0.036451	10494.02
F-statistic	2.232493	2.568492	2.167199	2.025739	6.187630
Log likelihood	206.9588	277.2970	165.7492	185.3752	-857.9639
Akaike AIC	-3.999006	-5.693903	-3.006004	-3.478920	21.66178
Schwarz SC	-2.804157	-4.499054	-1.811155	-2.284071	22.85663
Determinant residual covariance		8.25E-07			
Log likelihood		-7.521545			
Akaike information criterion		5.121001			
Schwarz criterion		11.09525			

Note: Standard errors are in ( ).

Table 13: VARX Model Estimates (Agricultural GDP Growth)

	Trade	Agr.GDP	Unemployment	Fixed Capital	Migration
Trade (-1)	-0.585753	-1.131769	0.257742	-0.055496	24049.38
	(0.09404)	(0.33374)	(0.15866)	(0.13836)	(38339)
Trade (-2)	-0.601669	-0.638370	0.073366	0.098730	-75031.31
	(0.09826)	(0.34871)	(0.16578)	(0.14457)	(40060)
Trade (-3)	-0.566221	-0.792833	0.146723	0.121391	22668.72
	(0.09128)	(0.32397)	(0.15402)	(0.13431)	(37217)
Trade (-4)	-0.372448	-0.991395	0.399074	0.078965	-55387.72
	(0.07996)	(0.28378)	(0.13491)	(0.11765)	(32600)
Agr.GDP (-1)	-0.064221	-0.341091	0.100497	0.023287	1858.227
	(0.02673)	(0.09488)	(0.04511)	(0.03934)	(10900)
Agr.GDP (-2)	-0.055555	-0.045749	0.109040	0.015751	-5847.028
	(0.02662)	(0.09447)	(0.04491)	(0.03917)	(10853)
Agr.GDP (-3)	-0.012339	-0.014977	0.007857	0.015164	-4132.944
	(0.02736)	(0.09710)	(0.04616)	(0.04026)	(11155)
Agr.GDP (-4)	0.048843	-0.281538	0.023409	0.020801	3297.608
	(0.02414)	(0.08568)	(0.04073)	(0.03552)	(9843.3)
Unemployment (-1)	-0.021313	-0.151974	-0.299044	-0.122534	-19668.85
	(0.06296)	(0.22344)	(0.10622)	(0.09263)	(25668)
Unemployment (-2)	-0.168514	-0.254946	-0.215023	-0.207682	-92213.81
	(0.06431)	(0.22825)	(0.10851)	(0.09463)	(26221)
Unemployment (-3)	-0.132964	-0.431046	0.145245	-0.243041	-10889.18
	(0.06008)	(0.21322)	(0.10137)	(0.08840)	(24495)
Unemployment (-4)	0.058382	-0.659878	-0.005536	-0.000237	-62549.36
	(0.05853)	(0.20773)	(0.09875)	(0.08612)	(23863)
Fixed Capital (-1)	-0.180775	-0.266319	-0.010338	0.086397	26609.16
	(0.08151)	(0.28929)	(0.13753)	(0.11994)	(33234)

Fixed Capital (-2)	-0.050225	-0.073811	-0.304277	0.182434	26455.50
	(0.06312)	(0.22401)	(0.10650)	(0.09287)	(25734)
Fixed Capital (-3)	-0.149202	0.573175	0.026903	-0.381087	32823.01
	(0.06754)	(0.23971)	(0.11396)	(0.09938)	(27537)
Fixed Capital (-4)	-0.246584	-0.736444	-0.026036	-0.121352	7876.764
	(0.07529)	(0.26722)	(0.12704)	(0.11079)	(30698)
Migration (-1)	2.93e-07	-2.67e-06	-3.96e-07	-8.07e-08	0.505633
	(2.62e-07)	(9.30e-07)	(4.42e-07)	(3.85e-07)	(0.10680)
Migration (-2)	-6.00e-07	8.27e-07	1.41e-06	1.98e-07	-0.140434
	(2.73e-07)	(9.70e-07)	(4.61e-07)	(4.02e-07)	(0.11138)
Migration (-3)	3.13e-07	7.11e-07	4.05e-07	-5.73e-08	0.384985
	(2.56e-07)	(9.09e-07)	(4.32e-07)	(3.77e-07)	(0.10439)
Migration (-4)	1.26e-07	7.35e-07	-8.83e-07	-1.05e-08	0.118931
	(2.52e-07)	(8.96e-07)	(4.26e-07)	(3.71e-07)	(0.10293)
C	-0.003094	0.023230	-0.037759	0.004910	6978.989
	(0.02739)	(0.09720)	(0.04621)	(0.04030)	(11167)
Oil Price	-0.047121	0.192124	-0.016526	-0.014229	6755.454
	(0.02652)	(0.09413)	(0.04475)	(0.03902)	(10813)
Oil Price (-1)	-0.123027	0.126858	0.017819	0.029051	4787.066
	(0.02482)	(0.08811)	(0.04189)	(0.03653)	(10121)
Oil Price (-2)	-0.058345	-0.108871	-0.087620	-0.034734	16843.33
	(0.02425)	(0.08608)	(0.04092)	(0.03569)	(9888.2)
Oil Price (-3)	-0.004927	-0.033396	-0.048669	0.074088	8598.771
	(0.02535)	(0.08996)	(0.04277)	(0.03729)	(10334)
Oil Price (-4)	-0.034937	0.122670	0.039135	-0.017165	-2280.519
	(0.02605)	(0.09244)	(0.04395)	(0.03832)	(10619)
World GDP	-9.898125	53.29691	-72.81799	14.24919	-4392480.
	(7.8736)	(27.9440)	(13.2878)	(11.5852)	(3210156)

World GDP (-1)	38.92028	-157.1408	138.8502	-28.09987	9994963.
	(17.1384)	(60.8248)	(28.9166)	(25.2171)	(6987443)
World GDP (-2)	-27.72730	134.6560	-88.46906	8.540662	-11717368
	(21.3371)	(75.7264)	(36.0009)	(31.3951)	(8699306)
World GDP (-3)	2.344706	5.258035	-22.28664	11.76290	6174303.
	(19.6491)	(69.7354)	(33.1527)	(28.9113)	(8011079)
World GDP (-4)	-0.280545	-52.87996	33.06994	-9.265547	-1259649.
	(8.4469)	(29.9784)	(14.2519)	(12.4286)	(3443858)
Temperature	0.000111	0.000244	0.000284	0.000766	-0.800616
	(0.00022)	(0.00077)	(0.00036)	(0.00032)	(87.883)
Temperature (-1)	4.39e-05	0.000402	-6.59e-05	-0.000558	-107.5245
	(0.00014)	(0.00049)	(0.00023)	(0.00020)	(56.631)
Temperature (-2)	-7.16e-05	0.000283	0.000575	0.000322	29.10682
	(0.00015)	(0.00052)	(0.00025)	(0.00021)	(59.203)
Temperature (-3)	-0.000132	-1.30e-05	0.000394	-0.000715	-72.97784
	(0.00014)	(0.00050)	(0.00024)	(0.00021)	(57.989)
Temperature (-4)	0.000268	-0.001021	-0.000232	-0.000188	85.79013
	(0.00023)	(0.00082)	(0.00039)	(0.00034)	(94.574)
Precipitation	-4.21e-06	0.000126	5.24e-05	2.10e-05	3.740988
	(0.0001)	(0.00005)	(0.00002)	(0.00002)	(5.6824)
Precipitation (-1)	-2.88e-05	3.32e-05	3.86e-05	-2.51e-05	0.783148
	(0.0001)	(0.00004)	(0.00002)	(0.00002)	(4.9554)
Precipitation (-2)	3.17e-05	-7.76e-05	-2.71e-05	5.79e-05	5.005813
	(0.0001)	(0.00004)	(0.00002)	(0.00002)	(5.1305)
Precipitation (-3)	8.75e-06	1.39e-05	-4.74e-05	1.19e-05	-2.657098
	(0.0001)	(0.00005)	(0.00002)	(0.00002)	(5.2144)
Precipitation (-4)	-1.44e-05	-3.56e-05	-2.15e-05	-1.67e-05	-5.757709
	(0.0002)	(0.00006)	(0.00003)	(0.00002)	(6.8997)

R-squared	0.714794	0.635623	0.693109	0.608263	0.845785
S.E. equation	0.026537	0.094183	0.044775	0.039047	10819.54
F-statistic	2.631546	1.831628	2.371408	1.630370	5.758674
Log likelihood	211.7200	106.5857	168.3031	179.6652	-860.4994
Akaike AIC	-4.113736	-1.580378	-3.067545	-3.341330	21.72288
Schwarz SC	-2.918887	-0.385529	-1.872696	-2.146481	22.91773

Determinant residual covariance	6.22E-05
Log likelihood	-186.9562
Akaike information criterion	9.444728
Schwarz criterion	15.41897

Note: Standard errors are in ( ).

Table 14: VARX Model Estimates (Non-agricultural GDP Growth)

	Trade	Non-agr.GDP	Unemployment	Fixed Capital	Migration
Trade (-1)	-0.607708	0.046576	0.215143	0.126560	66065.79
	(0.10716)	(0.04727)	(0.17706)	(0.14069)	(40222)
Trade (-2)	-0.617710	0.056656	0.078627	0.181429	-47017.15
	(0.10940)	(0.04825)	(0.18076)	(0.14363)	(41063)
Trade (-3)	-0.592693	-0.022788	0.211589	0.215317	36160.88
	(0.09972)	(0.04398)	(0.16476)	(0.13092)	(37429)
Trade (-4)	-0.381721	0.064925	0.441098	0.197453	-13872.50
	(0.10352)	(0.04566)	(0.17105)	(0.13592)	(38858)
Non-agr.GDP (-1)	-0.103429	-0.168768	0.114419	1.087390	202819.8
	(0.25984)	(0.11461)	(0.42933)	(0.34115)	(97530)
Non-agr.GDP (-2)	0.102275	-0.108234	0.350753	0.248250	55378.75
	(0.24139)	(0.10647)	(0.39884)	(0.31692)	(90604)
Non-agr.GDP (-3)	0.089376	-0.551243	0.665259	0.059993	-58467.53
	(0.23694)	(0.10451)	(0.39150)	(0.31109)	(88936)
Non-agr.GDP (-4)	-0.118459	-0.229324	0.405188	0.132436	70173.59
	(0.25956)	(0.11449)	(0.42887)	(0.34078)	(97426)
Unemployment (-1)	-0.042276	-0.032612	-0.284753	-0.061532	-11414.08
	(0.06740)	(0.02973)	(0.11136)	(0.08849)	(25297)
Unemployment (-2)	-0.152719	-0.010999	-0.183651	-0.102018	-73533.55
	(0.07210)	(0.03180)	(0.11913)	(0.09466)	(27062)
Unemployment (-3)	-0.117494	-0.056995	0.180176	-0.213268	-4300.002
	(0.06613)	(0.02917)	(0.10926)	(0.08682)	(24820)
Unemployment (-4)	0.084279	-0.040436	0.008051	0.010646	-57429.89
	(0.06549)	(0.02888)	(0.10820)	(0.08598)	(24581)

Fixed Capital (-1)	-0.138057	0.055238	-0.068725	-0.007302	1850.841
	(0.09071)	(0.04000)	(0.14987)	(0.11909)	(34046)
Fixed Capital (-2)	-0.032111	0.100424	-0.369531	0.152841	25115.88
	(0.06483)	(0.02859)	(0.10711)	(0.08511)	(24333)
Fixed Capital (-3)	-0.146152	0.026660	-0.005631	-0.457408	26407.20
	(0.07348)	(0.03241)	(0.12141)	(0.09647)	(27581)
Fixed Capital (-4)	-0.290327	0.088758	-0.065364	-0.114842	4142.011
	(0.08201)	(0.03617)	(0.13551)	(0.10767)	(30783)
Migration (-1)	1.27E-07	-3.00E-07	-3.77E-07	-1.71E-07	0.498088
	(2.84e-07)	(1.25e-07)	(4.69e-07)	(3.73e-07)	(0.10660)
Migration (-2)	-4.47E-07	4.01E-07	1.06E-06	5.78E-07	-0.078948
	(2.91e-07)	(1.28e-07)	(4.81e-07)	(3.82e-07)	(0.10920)
Migration (-3)	5.33E-07	-1.69E-07	1.98E-07	-4.25E-07	0.346518
	(2.69e-07)	(1.19e-07)	(4.44e-07)	(3.53e-07)	(0.10088)
Migration (-4)	-3.67E-08	2.36E-08	-5.79E-07	1.15E-08	0.109872
	(2.53e-07)	(1.12e-07)	(4.19e-07)	(3.33e-07)	(0.09509)
C	0.001794	0.023016	-0.069672	-0.015748	5190.717
	(0.02852)	(0.01258)	(0.04712)	(0.03744)	(10704)
Oil Price	-0.036656	0.012852	-0.021770	-0.012038	4941.543
	(0.02769)	(0.01221)	(0.04575)	(0.03636)	(10394)
Oil Price (-1)	-0.108681	0.014719	0.024874	0.003369	3983.956
	(0.02607)	(0.01150)	(0.04308)	(0.03423)	(9785.5)
Oil Price (-2)	-0.067007	0.000704	-0.081765	-0.050990	14327.08
	(0.02553)	(0.01126)	(0.04218)	(0.03352)	(9581.6)
Oil Price (-3)	-0.024776	0.014829	-0.076122	0.075543	11457.35
	(0.02772)	(0.01222)	(0.04580)	(0.03639)	(10404)
Oil Price (-4)	-0.040128	0.021575	0.036964	0.004993	958.6544
	(0.02841)	(0.01253)	(0.04694)	(0.03730)	(10664)

World GDP	-13.49909	12.74073	-66.53341	21.67492	-2911702.
	(8.4192)	(3.7135)	(13.9108)	(11.0537)	(3160123)
World GDP (-1)	42.08092	-36.37034	135.5944	-46.18201	6358649.
	(19.0409)	(8.3985)	(31.4609)	(24.9992)	(7146973)
World GDP (-2)	-20.83293	36.65690	-97.78015	30.68275	-7676624.
	(24.069)	(10.6163)	(39.7687)	(31.6006)	(9034255)
World GDP (-3)	-8.840685	-10.32230	-15.32479	-8.272735	2812298.
	(22.193)	(9.7888)	(36.6690)	(29.1376)	(8330103)
World GDP (-4)	5.304185	-5.279174	33.78268	1.667592	611876.2
	(10.001)	(4.4114)	(16.5251)	(13.1310)	(3754007)
Temperature	-8.81E-05	6.79E-05	0.000215	0.000834	33.11104
	(0.00023)	(0.00010)	(0.00038)	(0.00030)	(86.7616)
Temperature (-1)	7.76E-05	-0.000103	-9.96E-05	-0.000564	-100.0698
	(0.00015)	(0.00007)	(0.00025)	(0.00020)	(56.7668)
Temperature (-2)	-6.06E-05	1.38E-05	0.000522	0.000396	30.70388
	(0.00016)	(0.00007)	(0.00026)	(0.00020)	(59.1350)
Temperature (-3)	-0.000127	-8.26E-05	0.000445	-0.000698	-57.99182
	(0.00015)	(0.00007)	(0.00025)	(0.00020)	(57.6998)
Temperature (-4)	0.000385	-0.000165	-0.000208	-0.000307	40.13887
	(0.00025)	(0.00010)	(0.00041)	(0.00032)	(93.0093)
Precipitation	-1.23E-05	-7.31E-06	6.13E-05	3.19E-05	4.619095
	(0.00001)	(6.48e-06)	(0.00002)	(0.00002)	(5.5170)
Precipitation (-1)	-3.05E-05	4.10E-06	4.91E-05	-1.47E-05	2.937069
	(0.00001)	(5.79e-06)	(0.00002)	(0.00002)	(4.9286)
Precipitation (-2)	2.09E-05	1.99E-06	-1.40E-05	5.52E-05	3.884405
	(0.00001)	(5.67e-06)	(0.00002)	(0.00002)	(4.8270)
Precipitation (-3)	1.01E-05	3.70E-07	-4.11E-05	4.63E-06	-4.429616
	(0.00001)	(5.87e-06)	(0.00002)	(0.00002)	(4.9985)

Precipitation (-4)	-1.28E-06	1.07E-05	-2.32E-05	-2.10E-05	-7.549044
	(0.00002)	(7.69e-06)	(0.00003)	(0.00003)	(6.5472)
R-squared	0.680640	0.702136	0.670453	0.650748	0.853641
S.E. equation	0.028082	0.012386	0.046398	0.036869	10540.34
F-statistic	2.237828	2.475099	2.136191	1.956423	6.124161
Log likelihood	207.0262	274.9648	165.3473	184.4292	-858.3294
Akaike AIC	-4.000630	-5.637706	-2.996320	-3.456126	21.67059
Schwarz SC	-2.805781	-4.442857	-1.801471	-2.261277	22.86544
Determinant residual covariance		9.28E-07			
Log likelihood		-12.41515			
Akaike information criterion		5.238919			
Schwarz criterion		11.21316			

Note: Standard errors are in ( ).

Appendix B

Table 15: Residual Correlation Matrix for VARX Model (Total GDP)

	Trade	GDP Growth	Unemployment	Fixed Capital	Migration
Trade	1	-0.3501	-0.1446	-0.1269	0.2161
GDP Growth	-0.3501	1	-0.0496	0.2198	0.0629
Unemployment	-0.1446	-0.0496	1	-0.0243	-0.2913
Fixed Capital	-0.1269	0.2198	-0.0243	1	-0.0679
Migration	0.2161	0.0630	-0.291	-0.0679	1

Table 16: Residual Correlation Matrix for VARX Model (Agricultural GDP)

	Trade	Agr. GDP Growth	Unemployment	Fixed Capital	Migration
Trade	1	-0.1028	-0.0913	-0.1417	0.1869
Agr. GDP Growth	-0.1028	1	-0.026	-0.1156	-0.0111
Unemployment	-0.0913	-0.0262	1	-0.0306	-0.2841
Fixed Capital	-0.1417	-0.1156	-0.031	1	0.0219
Migration	0.1869	-0.0111	-0.2841	0.0219	1

Table 17: Residual Correlation Matrix for VARX Model (Non-agricultural GDP)

	Trade	Non-agr. GDP Growth	Unemployment	Fixed Capital	Migration
Trade	1	-0.3260	-0.1484	-0.1401	0.2093
Non-agr. GDP Growth	-0.3260	1	-0.0247	0.2432	0.0749
Unemployment	-0.1484	-0.0247	1	-0.0035	-0.2755
Fixed Capital	-0.1401	0.2432	-0.0035	1	-0.0531
Migration	0.2093	0.0749	-0.2755	-0.0531	1

Table 18: Pairwise Granger Causality Tests for VARX Model

Null Hypothesis:	Obs	F-Statistic	Prob.
GDP GROWTH does not Granger Cause TRADE	84	0.10000	0.9821
TRADE does not Granger Cause GDP GROWTH		1.51326	0.2069
UNEMPLOYMENT does not Granger Cause TRADE	84	0.63207	0.6412
TRADE does not Granger Cause UNEMPLOYMENT		0.13522	0.9689
FIXED CAPITAL does not Granger Cause TRADE	84	1.50221	0.2101
TRADE does not Granger Cause FIXED CAPITAL		0.37259	0.8275
MIGRATION does not Granger Cause TRADE	84	1.70397	0.1580
TRADE does not Granger Cause MIGRATION		2.20404	0.0766
UNEMPLOYMENT does not Granger Cause GDP GROWTH	84	1.35323	0.2583
GDP GROWTH does not Granger Cause UNEMPLOYMENT		1.47651	0.2178
FIXED CAPITAL does not Granger Cause GDP GROWTH	84	1.73750	0.1506
GDP GROWTH does not Granger Cause FIXED CAPITAL		1.70870	0.1570
MIGRATION does not Granger Cause GDP GROWTH	84	1.87486	0.1237
GDP GROWTH does not Granger Cause MIGRATION		4.73280	0.0018
FIXED CAPITAL does not Granger Cause UNEMPLOYMENT	84	1.80752	0.1362
UNEMPLOYMENT does not Granger Cause FIXED CAPITAL		3.79274	0.0073
MIGRATION does not Granger Cause UNEMPLOYMENT	84	1.00011	0.4130
UNEMPLOYMENT does not Granger Cause MIGRATION		6.04205	0.0003
MIGRATION does not Granger Cause FIXED CAPITAL	84	0.82587	0.5128
FIXED CAPITAL does not Granger Cause MIGRATION		2.82882	0.0304

Appendix C

Table 19: Economic Impact (Compared with the Baseline) on Total GDP Growth under Each Scenario, 2000 Q1 to 2007 Q4

Time	Scenario 1	Scenario 2	Scenario 3	Scenario 4
2000 Q1	0.000	-0.001	-0.001	0.001
2000 Q2	0.002	-0.001	0.001	0.003
2000 Q3	0.001	0.000	0.001	0.001
2000 Q4	-0.003	0.003	-0.001	-0.006
2001 Q1	-0.003	0.002	-0.001	-0.005
2001 Q2	-0.007	0.003	-0.004	-0.010
2001 Q3	-0.009	0.004	-0.005	-0.014
2001 Q4	-0.005	0.002	-0.003	-0.007
2002 Q1	-0.002	0.001	-0.001	-0.003
2002 Q2	-0.010	0.002	-0.007	-0.013
2002 Q3	-0.010	0.004	-0.007	-0.013
2002 Q4	-0.006	0.002	-0.003	-0.009
2003 Q1	-0.004	0.001	-0.002	-0.005
2003 Q2	-0.008	0.003	-0.005	-0.011
2003 Q3	-0.009	0.005	-0.004	-0.014
2003 Q4	-0.007	0.002	-0.004	-0.009
2004 Q1	-0.004	0.002	-0.001	-0.006
2004 Q2	-0.008	0.004	-0.005	-0.012
2004 Q3	-0.012	0.002	-0.010	-0.014
2004 Q4	-0.005	0.004	-0.001	-0.009
2005 Q1	-0.004	0.002	-0.002	-0.006
2005 Q2	-0.009	0.002	-0.006	-0.011
2005 Q3	-0.010	0.007	-0.004	-0.017
2005 Q4	-0.005	0.004	-0.001	-0.009
2006 Q1	-0.003	0.002	-0.001	-0.005
2006 Q2	-0.008	0.005	-0.003	-0.014
2006 Q3	-0.010	0.006	-0.004	-0.015
2006 Q4	-0.007	0.003	-0.004	-0.010
2007 Q1	-0.003	0.002	0.000	-0.005
2007 Q2	-0.011	0.002	-0.008	-0.014
2007 Q3	-0.011	0.006	-0.005	-0.017
2007 Q4	-0.005	0.004	-0.001	-0.009

Note: These figures are calculated by subtract the forecasts of each scenario from the baseline based on Table 9.

Table 20: Economic Impact (Compared with the Baseline) on Agricultural GDP Growth under Each Scenario, 2000 Q1 to 2007 Q4

Time	Scenario 1	Scenario 2	Scenario 3	Scenario 4
2000 Q1	0.001	0.018	0.019	-0.016
2000 Q2	0.01	0.052	0.061	-0.042
2000 Q3	0.027	0.06	0.086	-0.033
2000 Q4	0.031	-0.001	0.029	0.032
2001 Q1	0.011	-0.025	-0.013	0.035
2001 Q2	-0.024	0.03	0.006	-0.055
2001 Q3	-0.022	0.033	0.011	-0.055
2001 Q4	0.03	-0.002	0.029	0.032
2002 Q1	0.021	-0.001	0.02	0.023
2002 Q2	-0.025	0.031	0.006	-0.057
2002 Q3	-0.03	0.038	0.009	-0.068
2002 Q4	0.023	0	0.023	0.022
2003 Q1	0.012	-0.003	0.01	0.014
2003 Q2	-0.02	0.048	0.028	-0.068
2003 Q3	-0.024	0.027	0.003	-0.051
2003 Q4	0.026	-0.006	0.02	0.033
2004 Q1	0.015	-0.002	0.012	0.017
2004 Q2	-0.025	0.029	0.005	-0.054
2004 Q3	-0.032	0.071	0.039	-0.103
2004 Q4	0.025	0.008	0.033	0.017
2005 Q1	0.015	-0.021	-0.006	0.037
2005 Q2	-0.028	0.065	0.038	-0.093
2005 Q3	-0.023	0.061	0.037	-0.084
2005 Q4	0.025	-0.02	0.005	0.044
2006 Q1	0.018	-0.02	-0.003	0.038
2006 Q2	-0.027	0.037	0.01	-0.064
2006 Q3	-0.019	0.049	0.03	-0.067
2006 Q4	0.026	0.006	0.032	0.02
2007 Q1	0.018	-0.011	0.007	0.029
2007 Q2	-0.035	0.059	0.024	-0.095
2007 Q3	-0.03	0.05	0.019	-0.08
2007 Q4	0.033	-0.021	0.012	0.054

Note: These figures are calculated by subtract the forecasts of each scenario from the baseline based on Table 10.

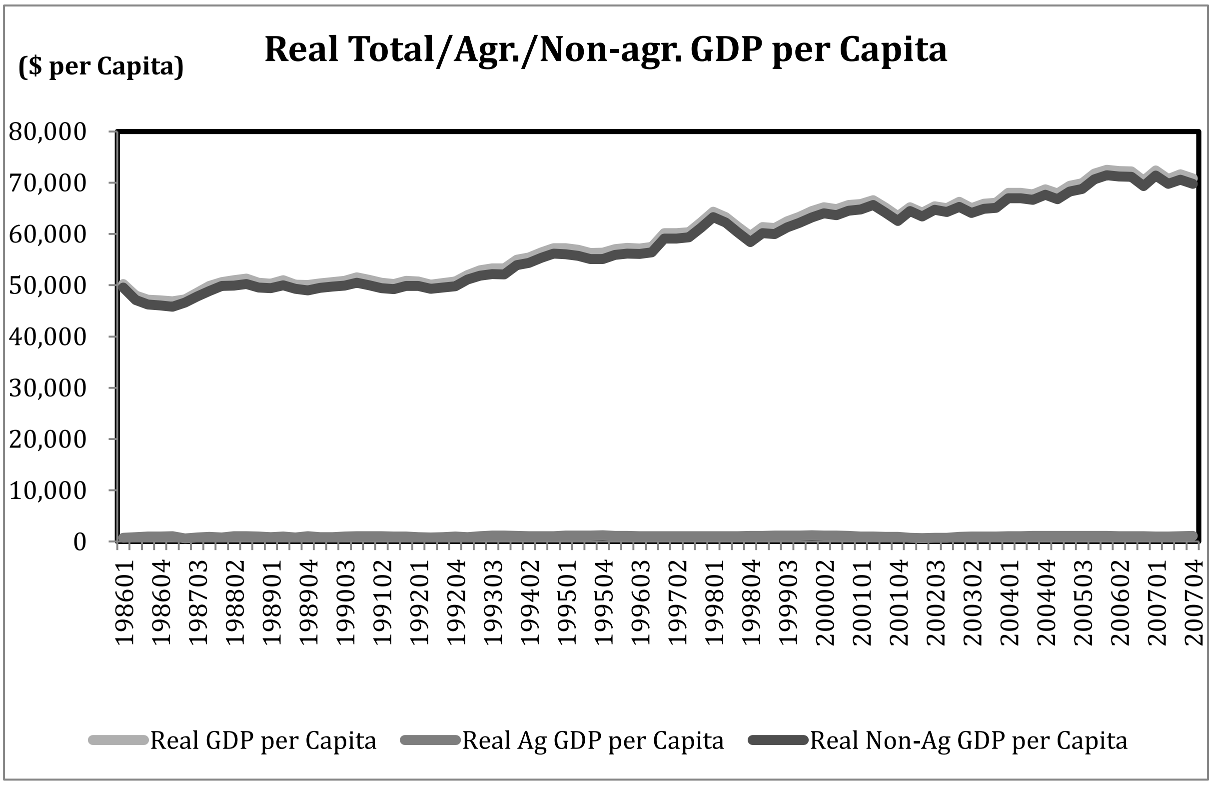
Table 21: Economic Impact (Compared with the Baseline) on Non-agricultural GDP Growth under Each Scenario, 2000 Q1 to 2007 Q4

Time	Scenario 1	Scenario 2	Scenario 3	Scenario 4
2000 Q1	0.0010	-0.0010	0.0000	0.0020
2000 Q2	0.0020	-0.0020	0.0000	0.0040
2000 Q3	0.0000	-0.0010	-0.0010	0.0020
2000 Q4	-0.0050	0.0020	-0.0030	-0.0070
2001 Q1	-0.0040	0.0020	-0.0010	-0.0060
2001 Q2	-0.0070	0.0020	-0.0050	-0.0090
2001 Q3	-0.0090	0.0040	-0.0050	-0.0130
2001 Q4	-0.0060	0.0020	-0.0040	-0.0080
2002 Q1	-0.0020	0.0010	-0.0020	-0.0030
2002 Q2	-0.0090	0.0020	-0.0070	-0.0110
2002 Q3	-0.0100	0.0020	-0.0080	-0.0130
2002 Q4	-0.0060	0.0030	-0.0030	-0.0090
2003 Q1	-0.0030	0.0020	-0.0020	-0.0050
2003 Q2	-0.0070	0.0020	-0.0060	-0.0090
2003 Q3	-0.0100	0.0040	-0.0050	-0.0140
2003 Q4	-0.0070	0.0030	-0.0050	-0.0100
2004 Q1	-0.0040	0.0030	-0.0010	-0.0060
2004 Q2	-0.0080	0.0030	-0.0050	-0.0110
2004 Q3	-0.0110	0.0010	-0.0100	-0.0120
2004 Q4	-0.0060	0.0040	-0.0020	-0.0100
2005 Q1	-0.0040	0.0020	-0.0020	-0.0060
2005 Q2	-0.0080	0.0000	-0.0080	-0.0090
2005 Q3	-0.0100	0.0060	-0.0040	-0.0150
2005 Q4	-0.0060	0.0040	-0.0010	-0.0110
2006 Q1	-0.0040	0.0020	-0.0020	-0.0070
2006 Q2	-0.0080	0.0050	-0.0030	-0.0120
2006 Q3	-0.0100	0.0040	-0.0060	-0.0150
2006 Q4	-0.0070	0.0030	-0.0050	-0.0100
2007 Q1	-0.0030	0.0020	-0.0010	-0.0060
2007 Q2	-0.0090	0.0020	-0.0080	-0.0110
2007 Q3	-0.0110	0.0050	-0.0060	-0.0160
2007 Q4	-0.0060	0.0050	-0.0010	-0.0100

Note: These figures are calculated by subtract the forecasts of each scenario from the baseline based on Table 11.

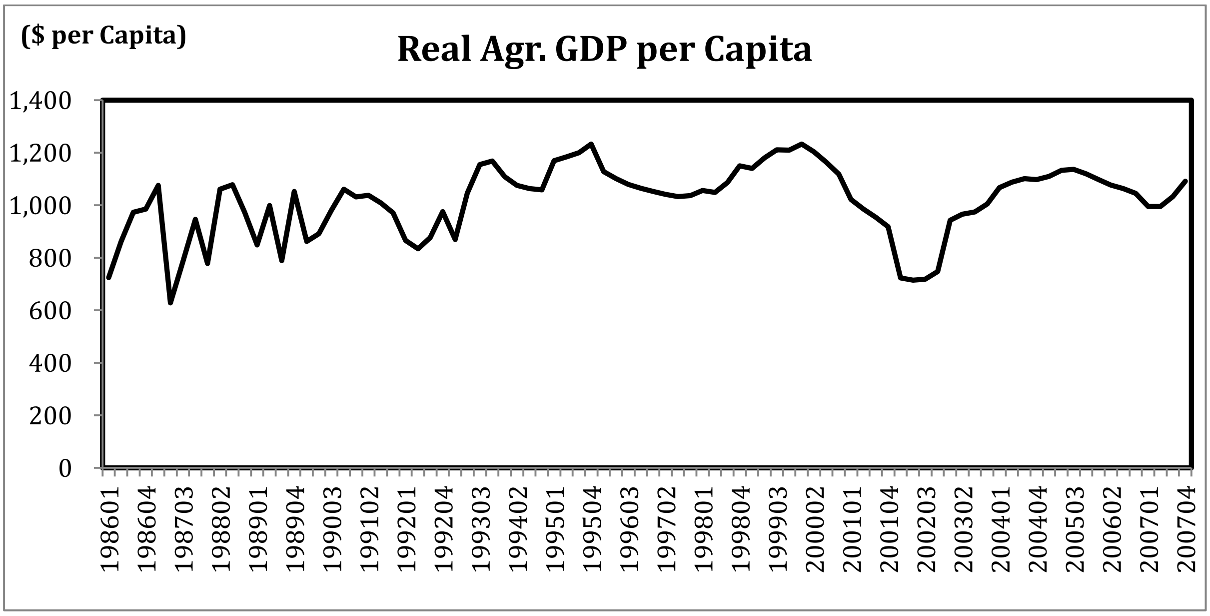
Appendix D

Figure 16: Plot of the Raw Data (Real Total GDP per Capita, Real Agricultural GDP per Capita and Real Non-Agricultural GDP per Capita), 1986 Q1 – 2007 Q



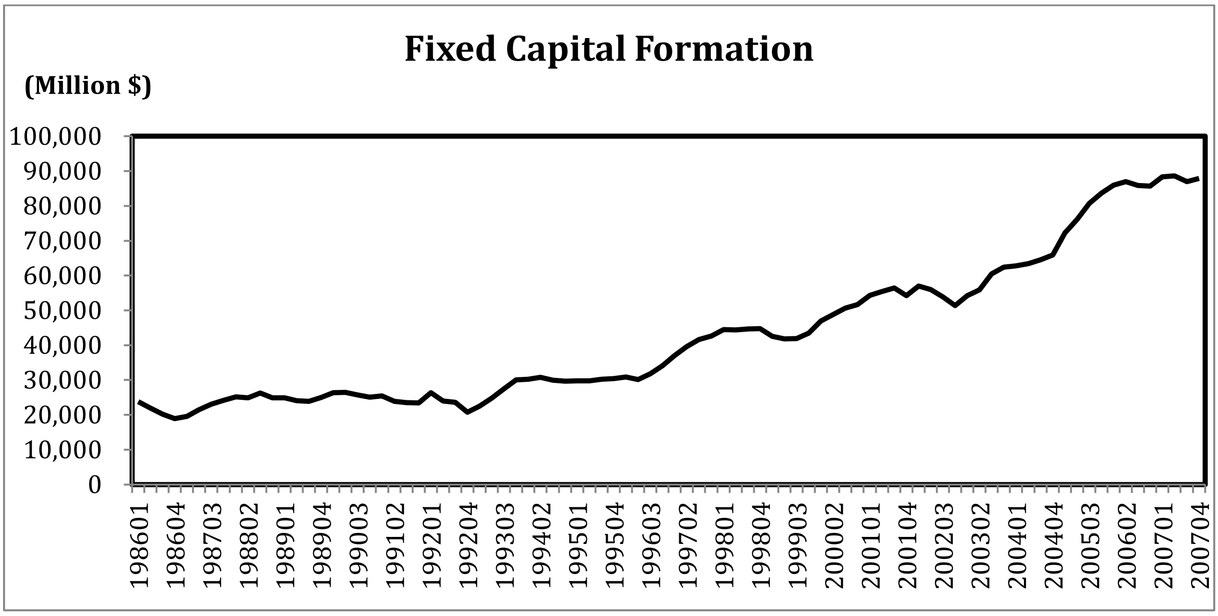
Data Source: The Conference Board of Canada (2015)

Figure 17: Plot of the Raw Data (Real Agricultural GDP per Capita), 1986 Q1 – 2007 Q4



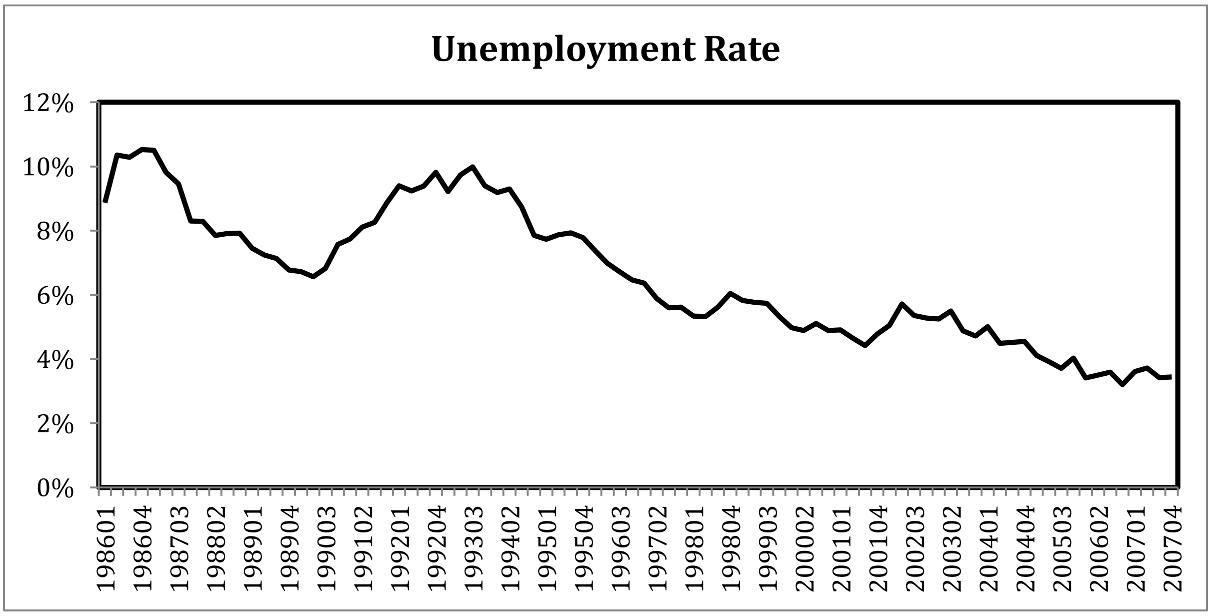
Data Source: The Conference Board of Canada (2015)

Figure 18: Plot of the Raw Data (Fixed Capital Formation), 1986 Q1 – 2007 Q4



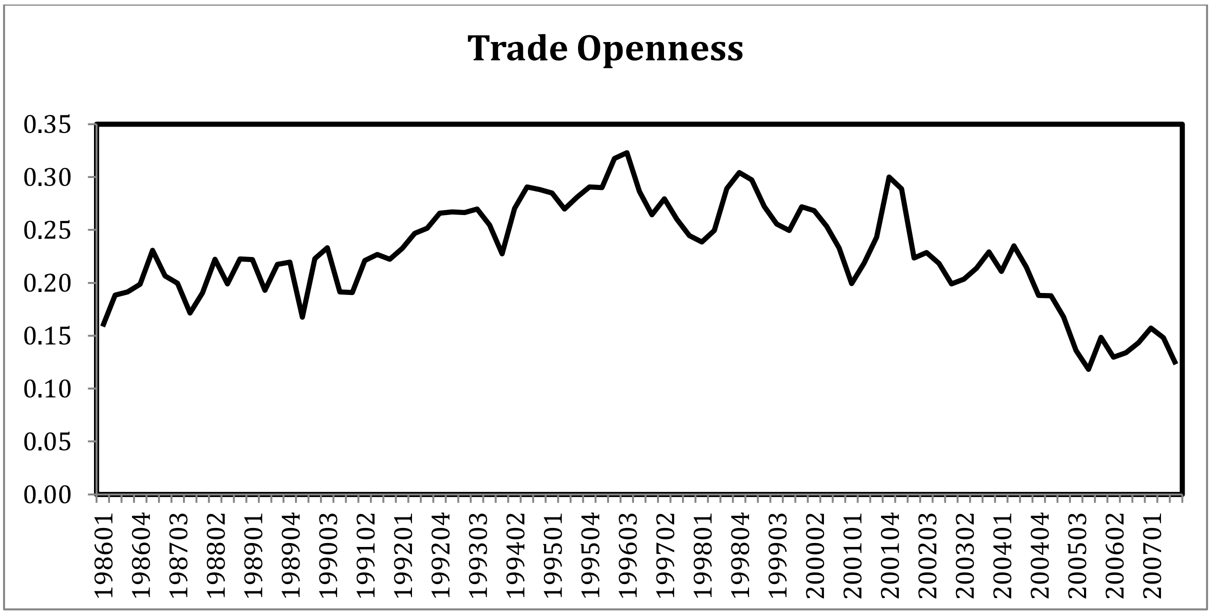
Data Source: The Conference Board of Canada (2015)

Figure 19: Plot of the Raw Data (Unemployment Rate), 1986 Q1 – 2007 Q4



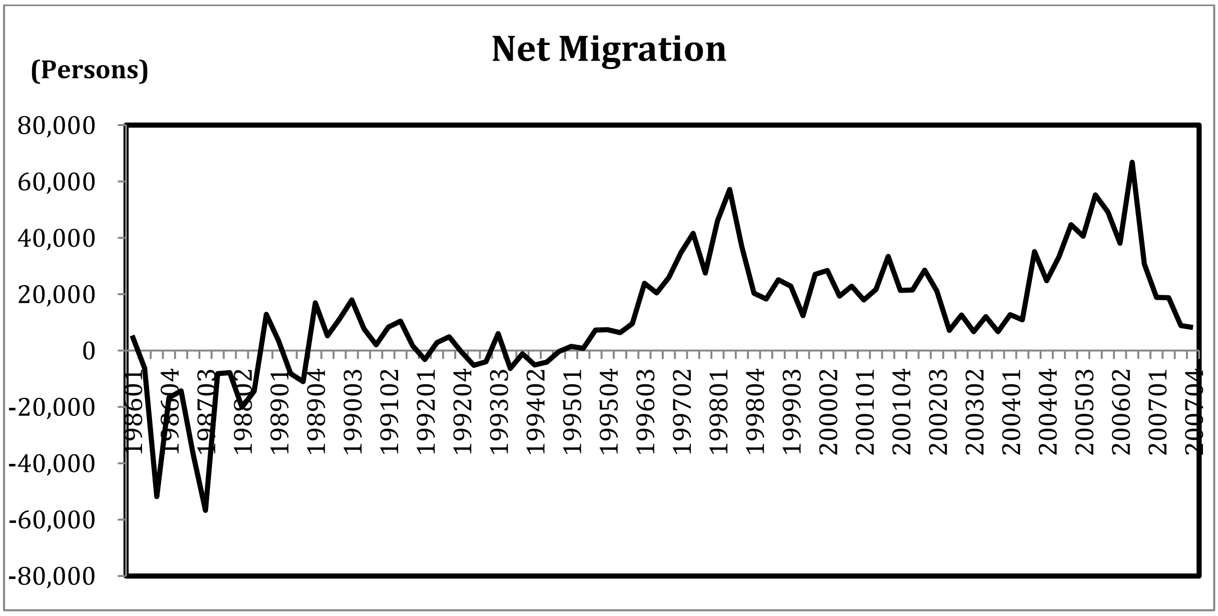
Data Source: The Conference Board of Canada (2015)

Figure 20: Plot of the Raw Data (Trade Openness), 1986 Q1 – 2007 Q4



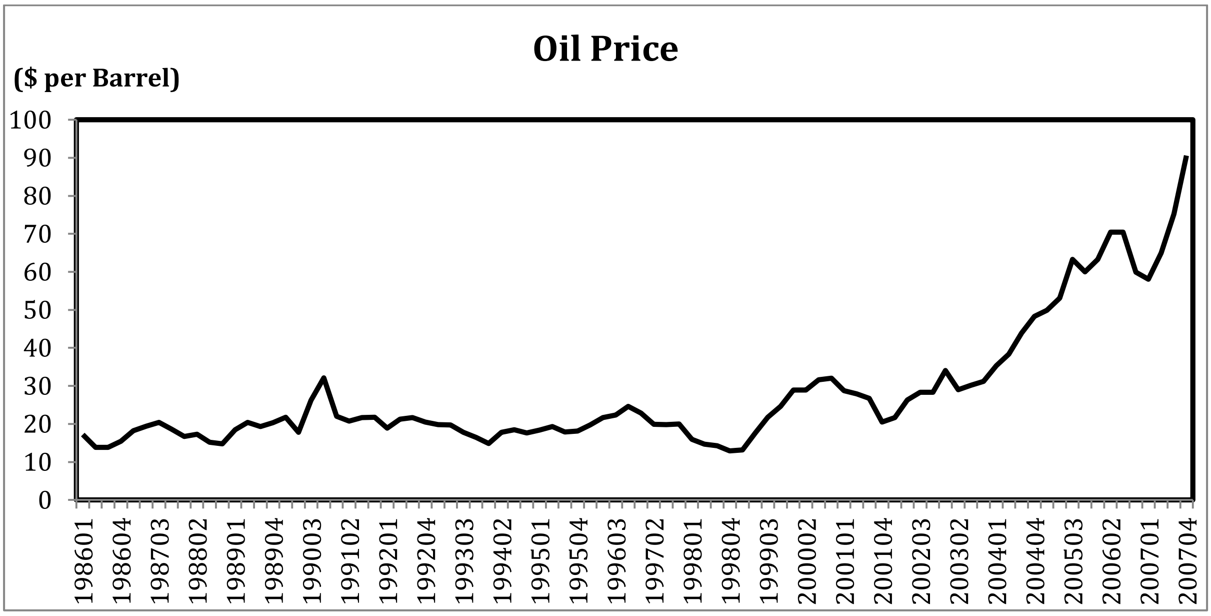
Data Source: The Conference Board of Canada (2015)

Figure 21: Plot of the Raw Data (Net Migration), 1986 Q1 – 2007 Q4



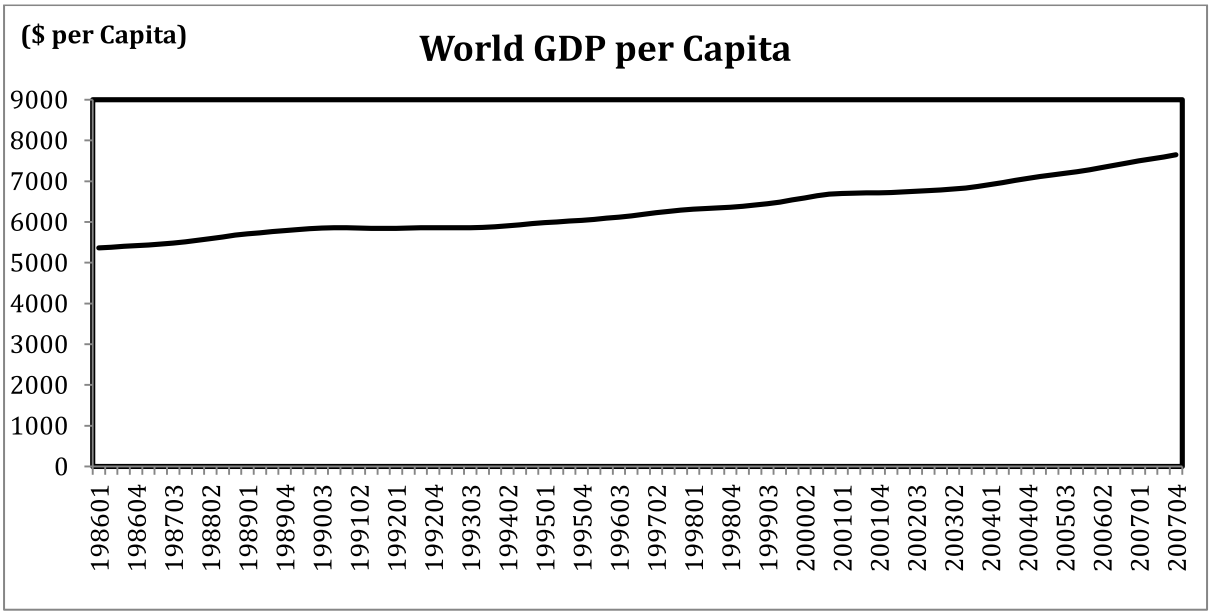
Data Source: The Conference Board of Canada (2015)

Figure 22: Plot of the Raw Data (Oil Price), 1986 Q1 – 2007 Q4



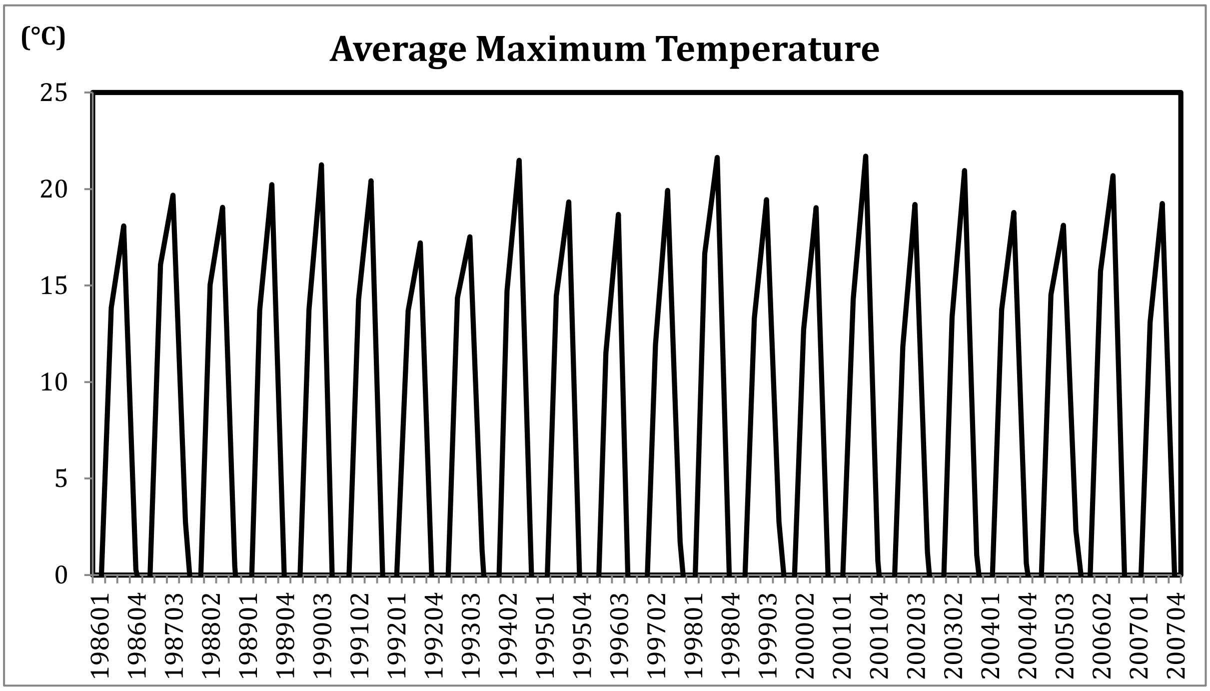
Data Source: US Energy Information Administration (2015)

Figure 23: Plot of the Raw Data (World GDP per Capita), 1986 Q1 – 2007 Q4



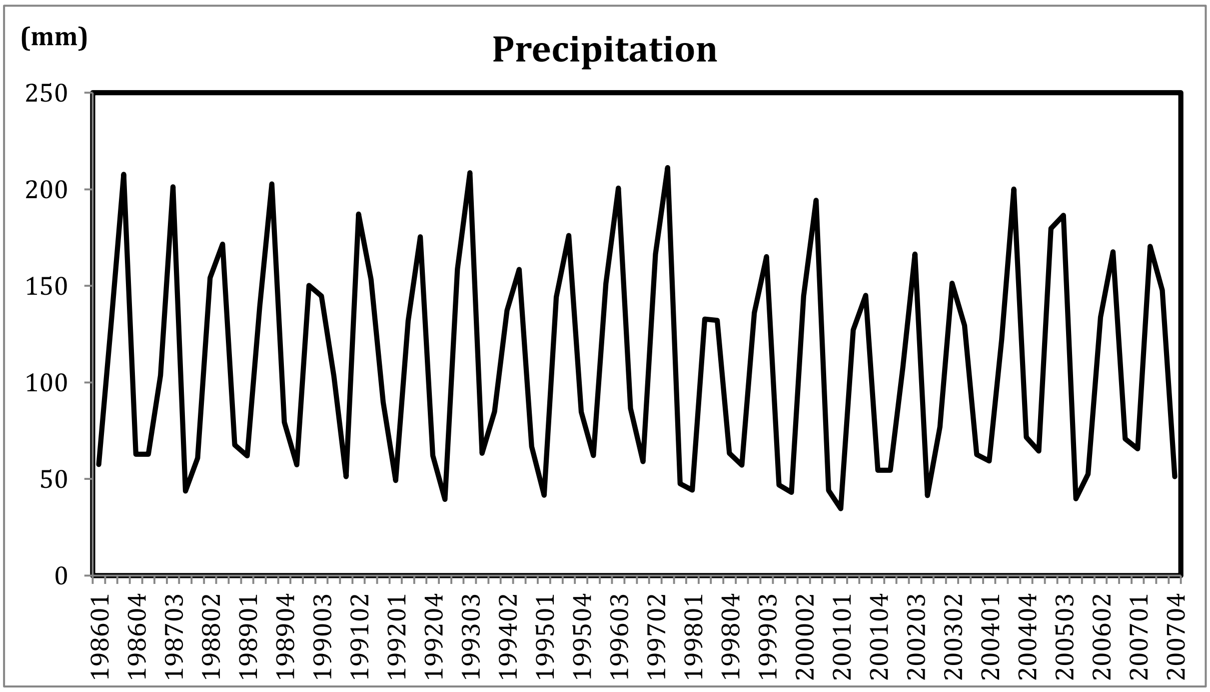
Data Source: World Development Indicators (2015)

Figure 24: Plot of the Raw Data (Average Maximum Temperature), 1986 Q1 – 2007 Q4



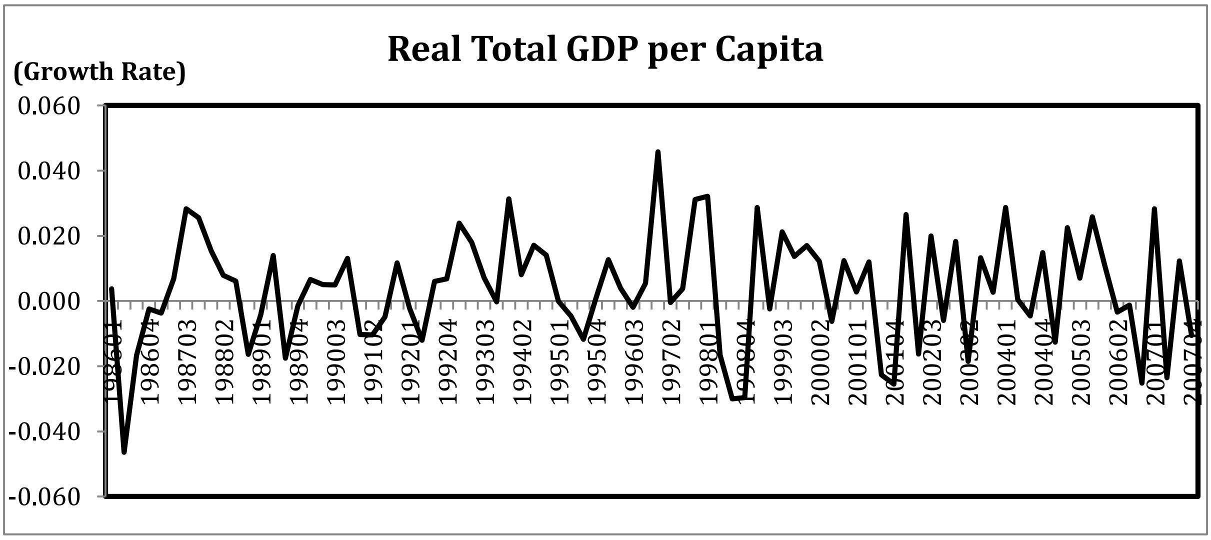
Data Source: Faramarzi et al. (2015)

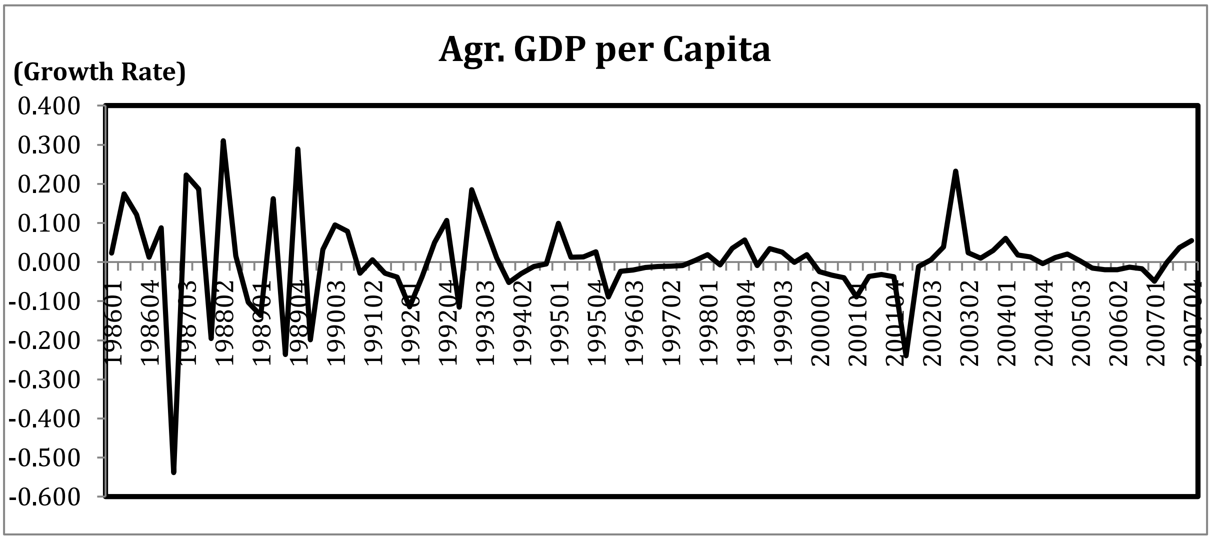
Figure 25: Plot of the Raw Data (Precipitation), 1986 Q1 – 2007 Q4

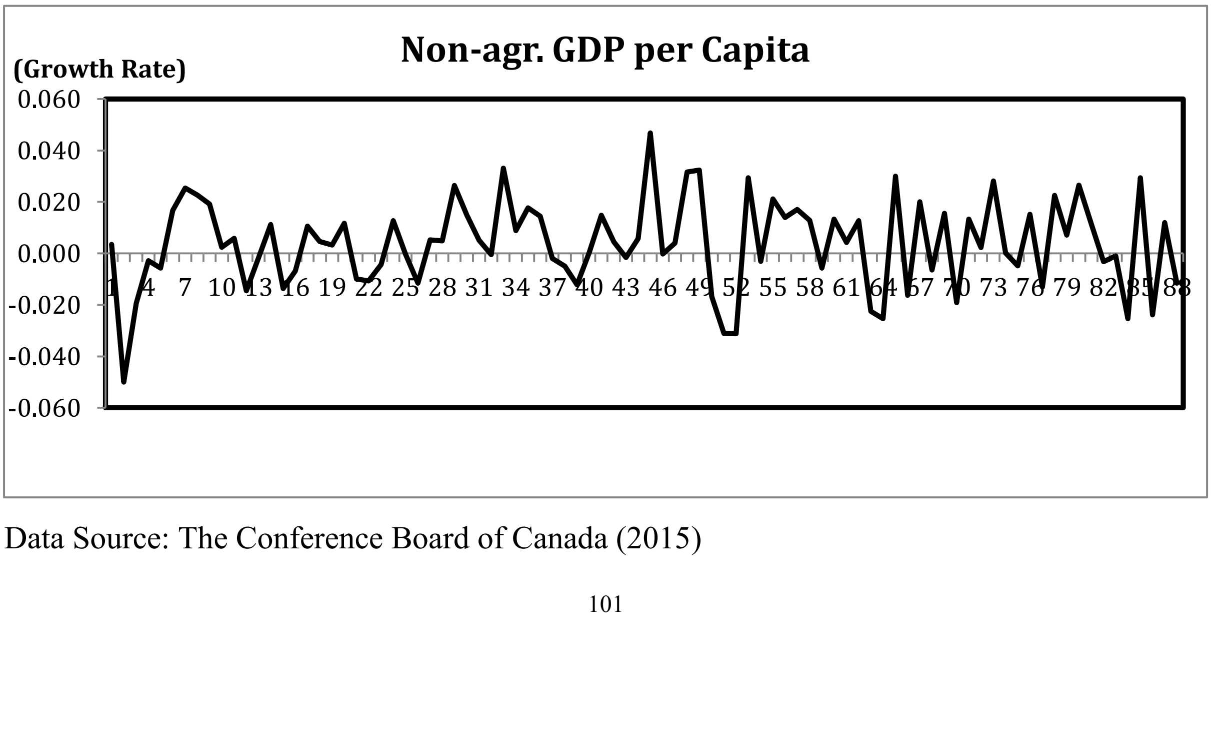


Data Source: Faramarzi et al. (2015)

Figure 26: Plot of the Variables Used in the VARX Model (Growth Rate of Real Total GDP per Capita, Real Agricultural GDP per Capita, and Real Non-Agricultural GDP per Capita), 1986 Q1 – 2007 Q4

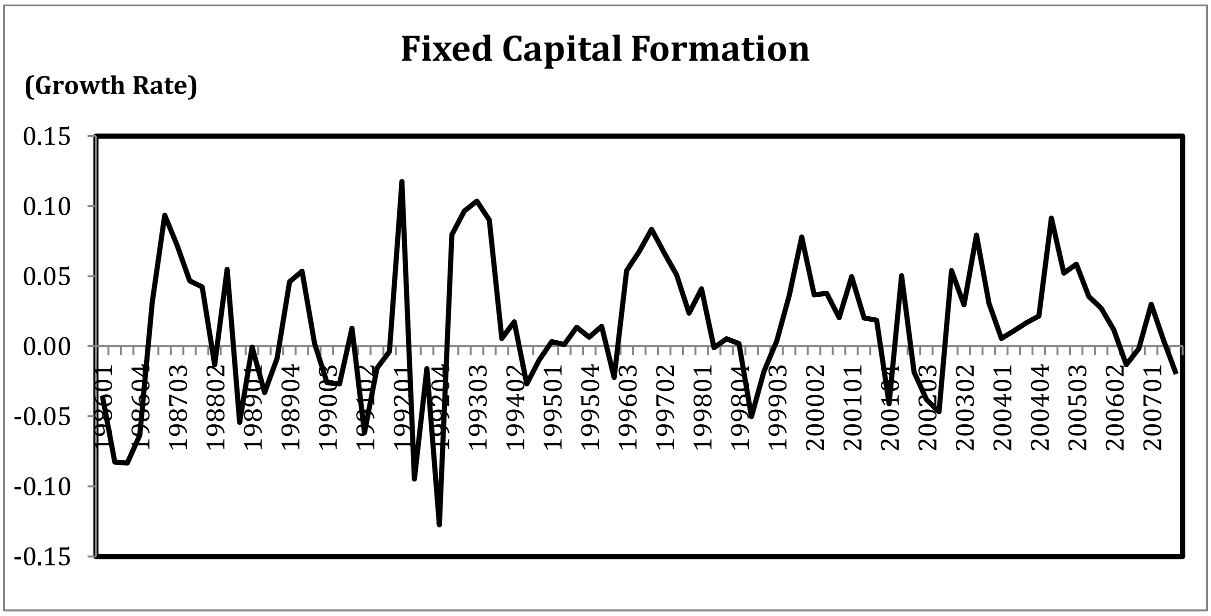






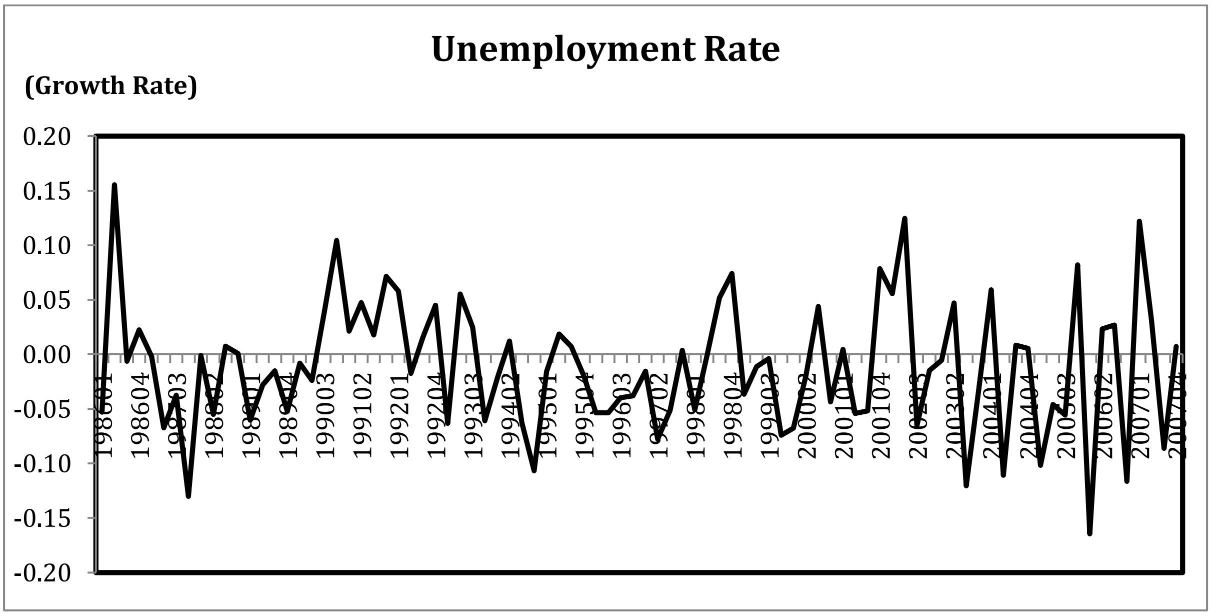
Data Source: The Conference Board of Canada (2015)

Figure 27: Plot of the Variables Used in the VARX Model (Growth Rate of Fixed Capital Formation), 1986 Q1 – 2007 Q4



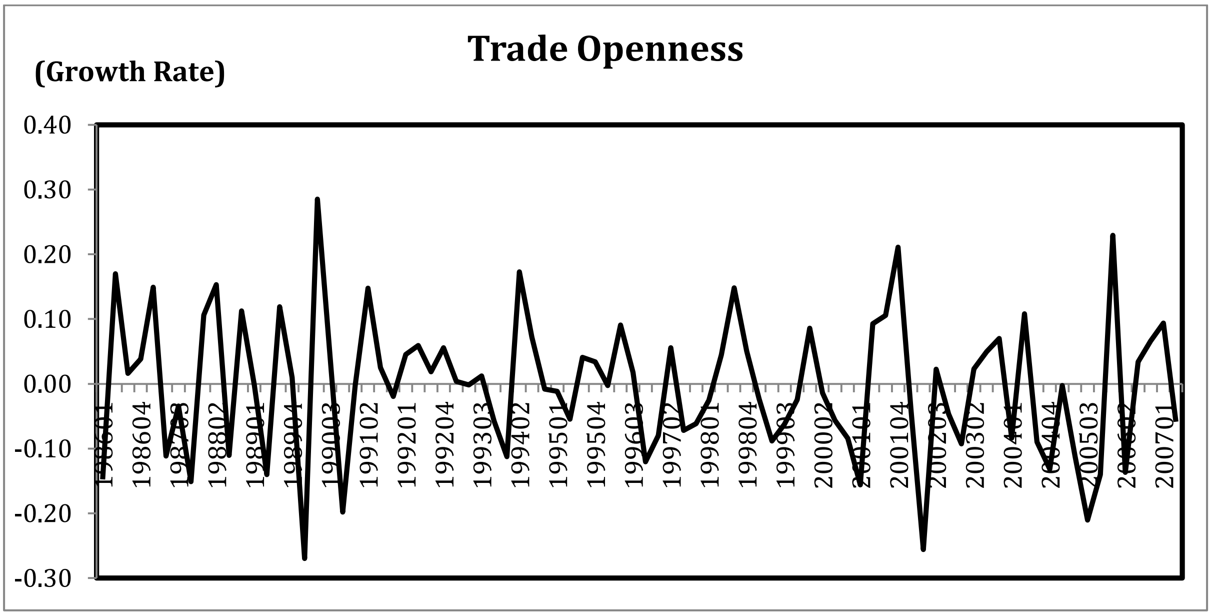
Data Source: The Conference Board of Canada (2015)

Figure 28: Plot of the Variables Used in the VARX Model (Growth Rate of Unemployment Rate), 1986 Q1 – 2007 Q4



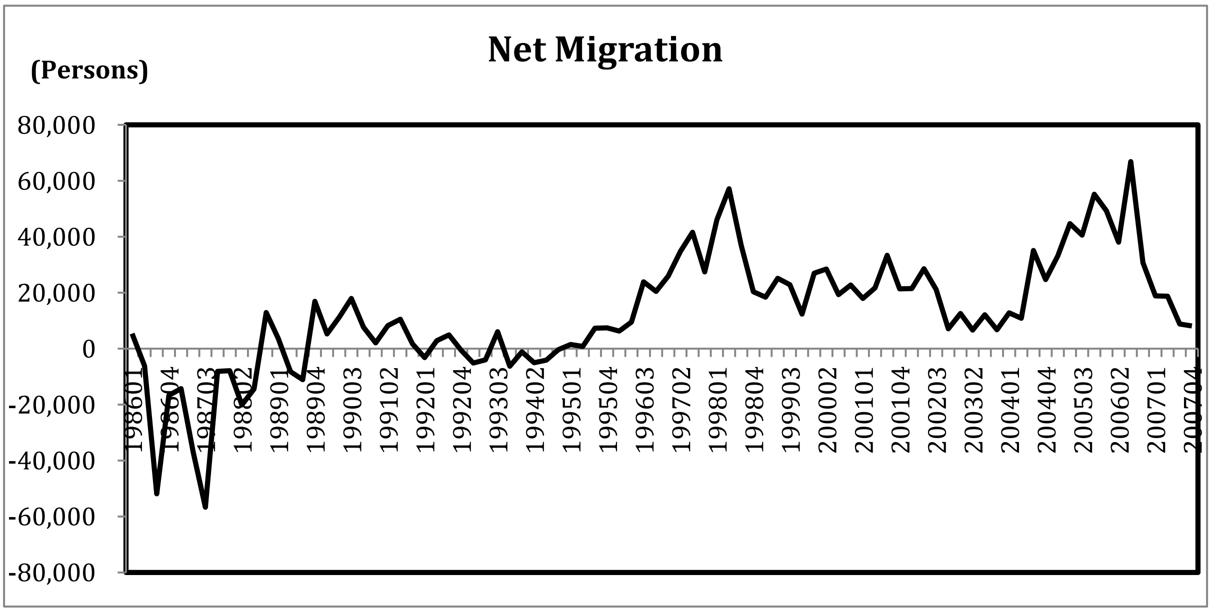
Data Source: The Conference Board of Canada (2015)

Figure 29: Plot of the Variables Used in the VARX Model (Growth Rate of Trade Openness), 1986 Q1 – 2007 Q4



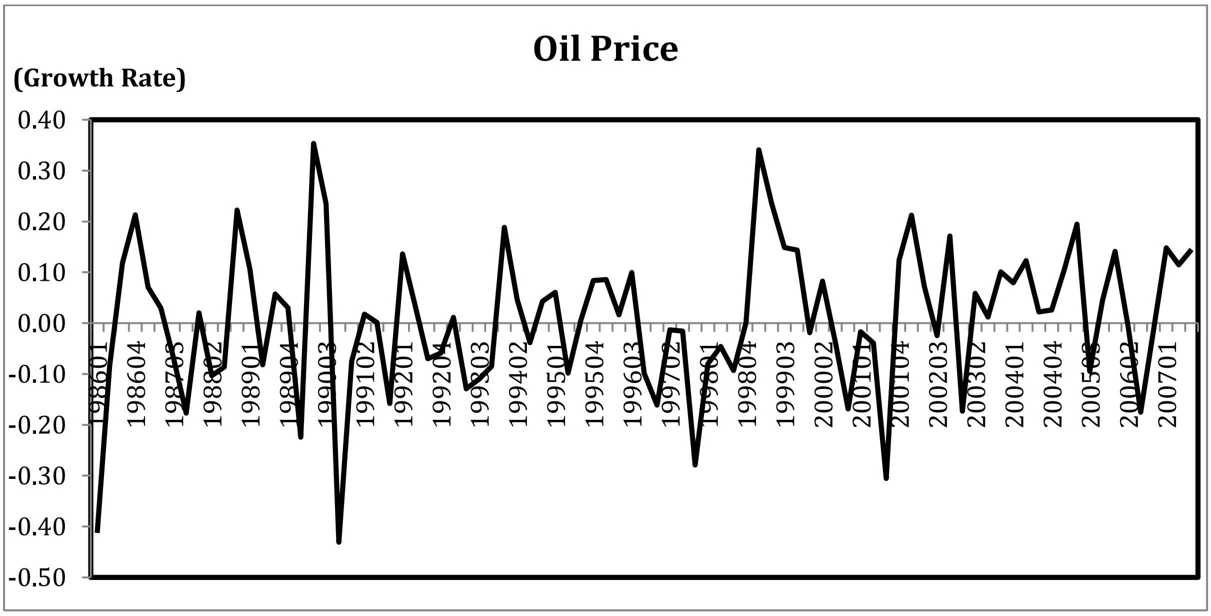
Data Source: The Conference Board of Canada (2015)

Figure 30: Plot of the Variables Used in the VARX Model (Net Migration), 1986 Q1 – 2007 Q4



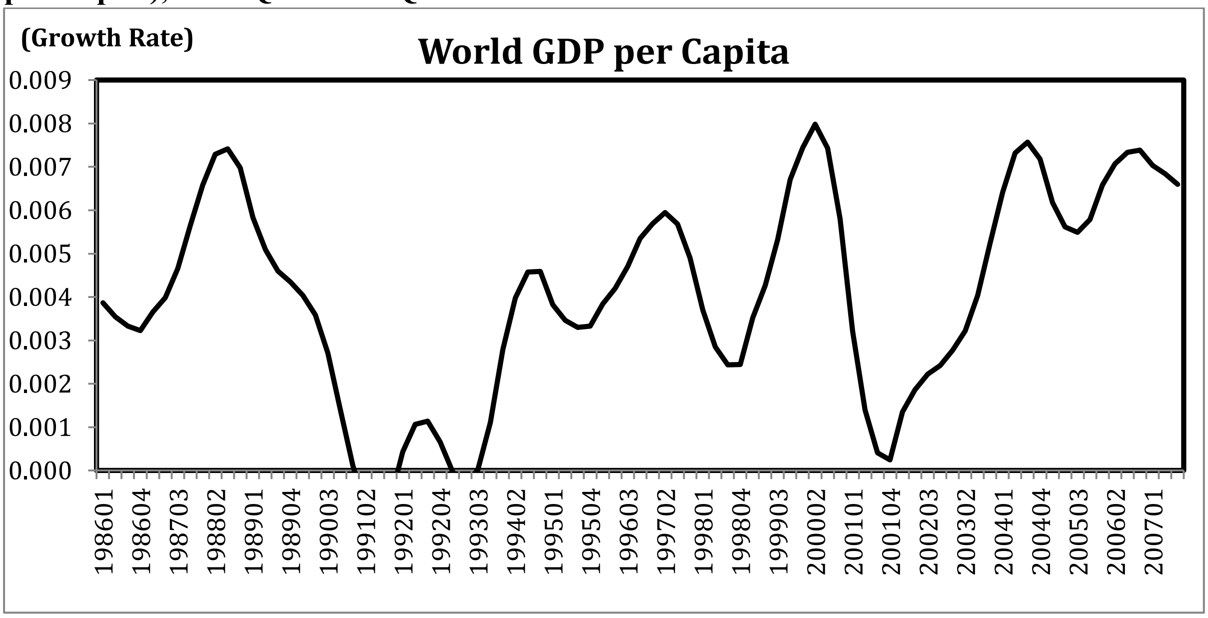
Data Source: The Conference Board of Canada (2015)

Figure 31: Plot of the Variables Used in the VARX Model (Growth Rate of Oil Price), 1986 Q1 – 2007 Q4



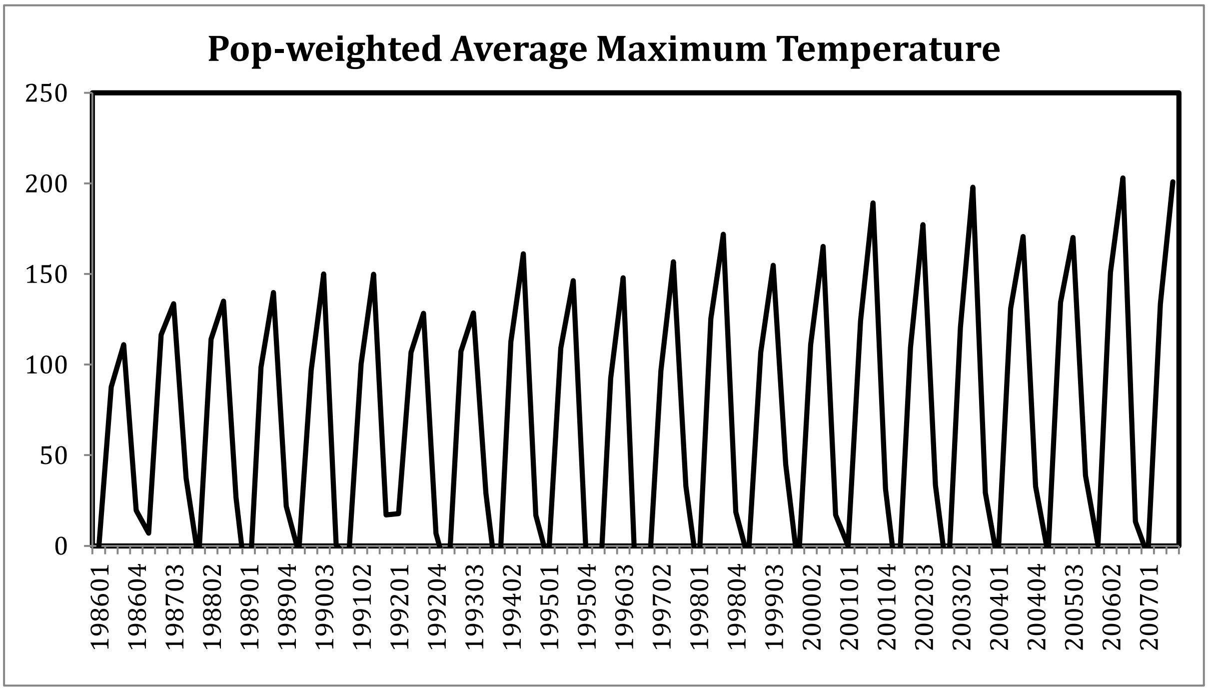
Data Source: US Energy Information Administration (2015)

Figure 32: Plot of the Variables Used in the VARX Model (Growth Rate of World GDP per Capita), 1986 Q1 – 2007 Q4



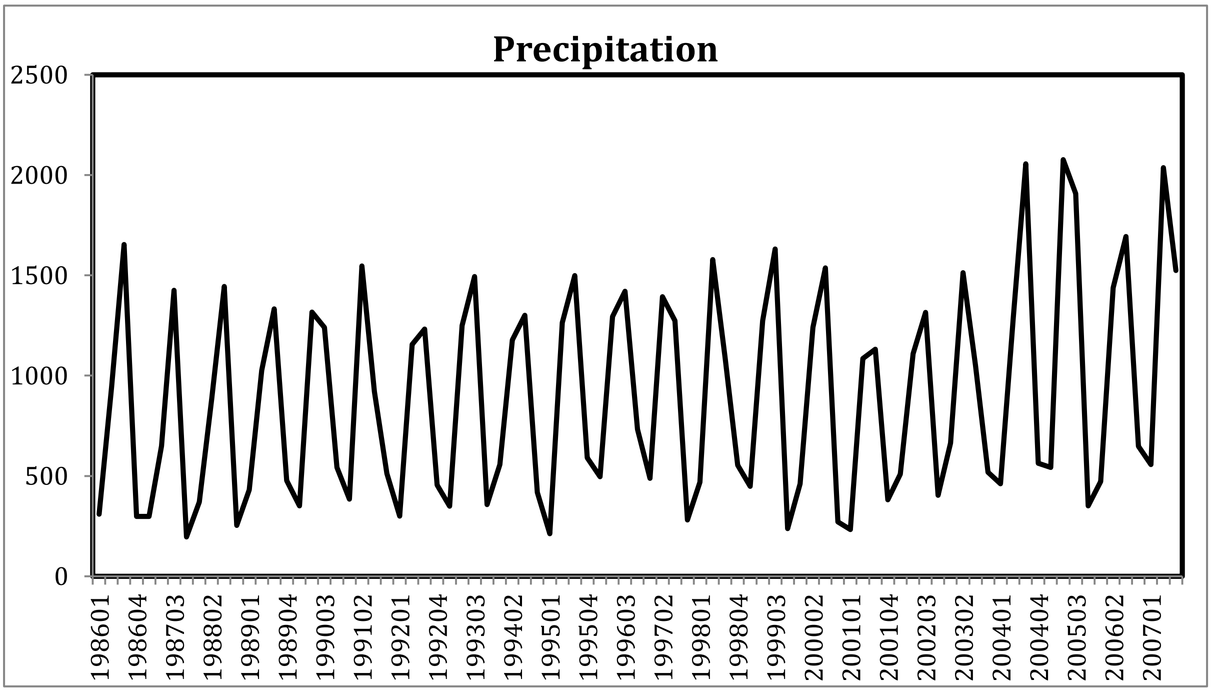
Data Source: World Development Indicators (2015)

Figure 33: Plot of the Variables Used in the VARX Model (Population-weighted Average Maximum Temperature), 1986 Q1 – 2007 Q4



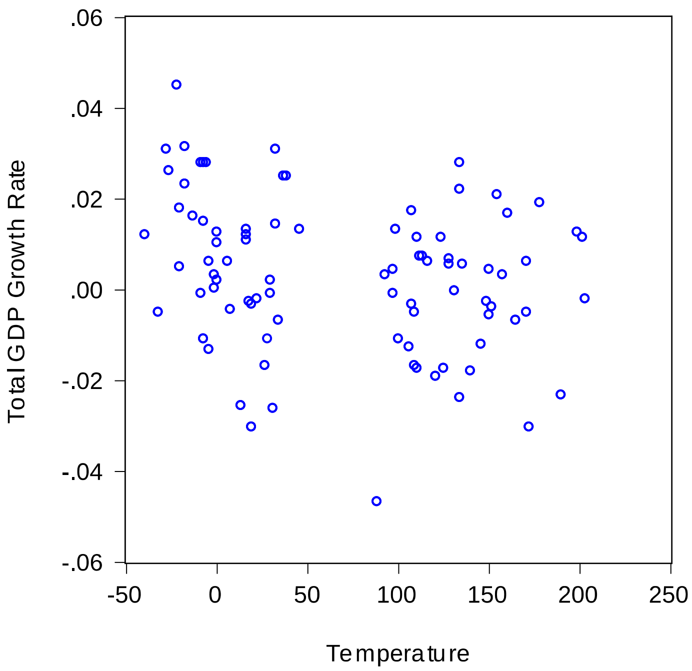
Data Source: Faramarzi et al. (2015)

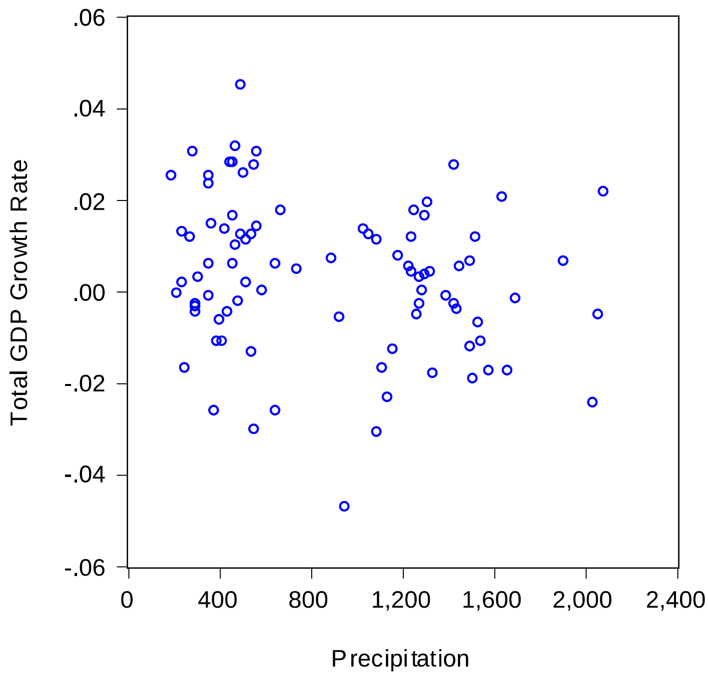
Figure 34: Plot of the Variables Used in the VARX Model (Population-weighted Average Maximum Precipitation), 1986 Q1 – 2007 Q4



Data Source: Faramarzi et al. (2015)

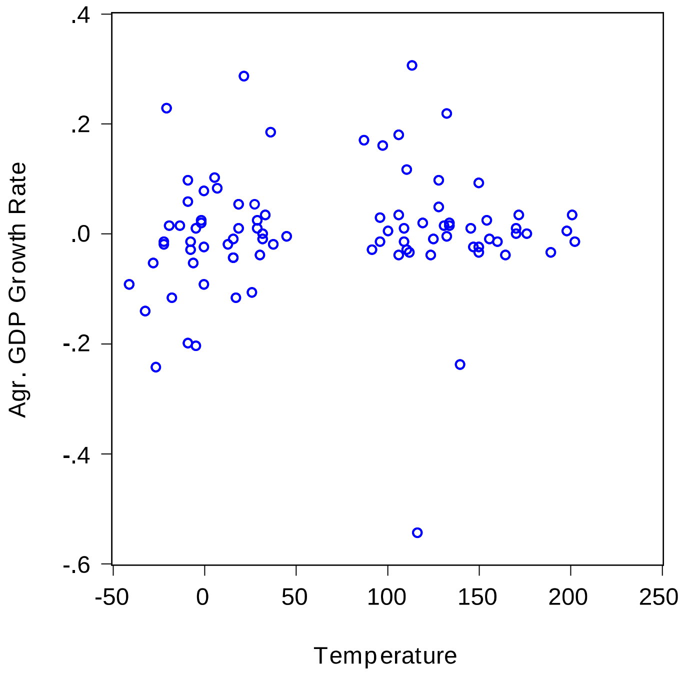
Figure 35: Scatterplot between Total GDP Growth Rate with Population-weighted Temperature and Precipitation, 1986 Q1 – 2007 Q4

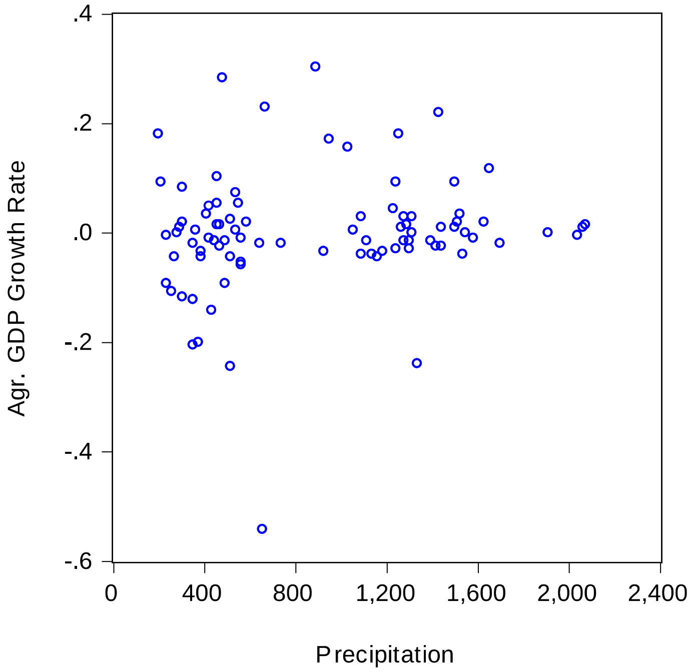




Data Source: The Conference Board of Canada (2015); Faramarzi et al. (2015)

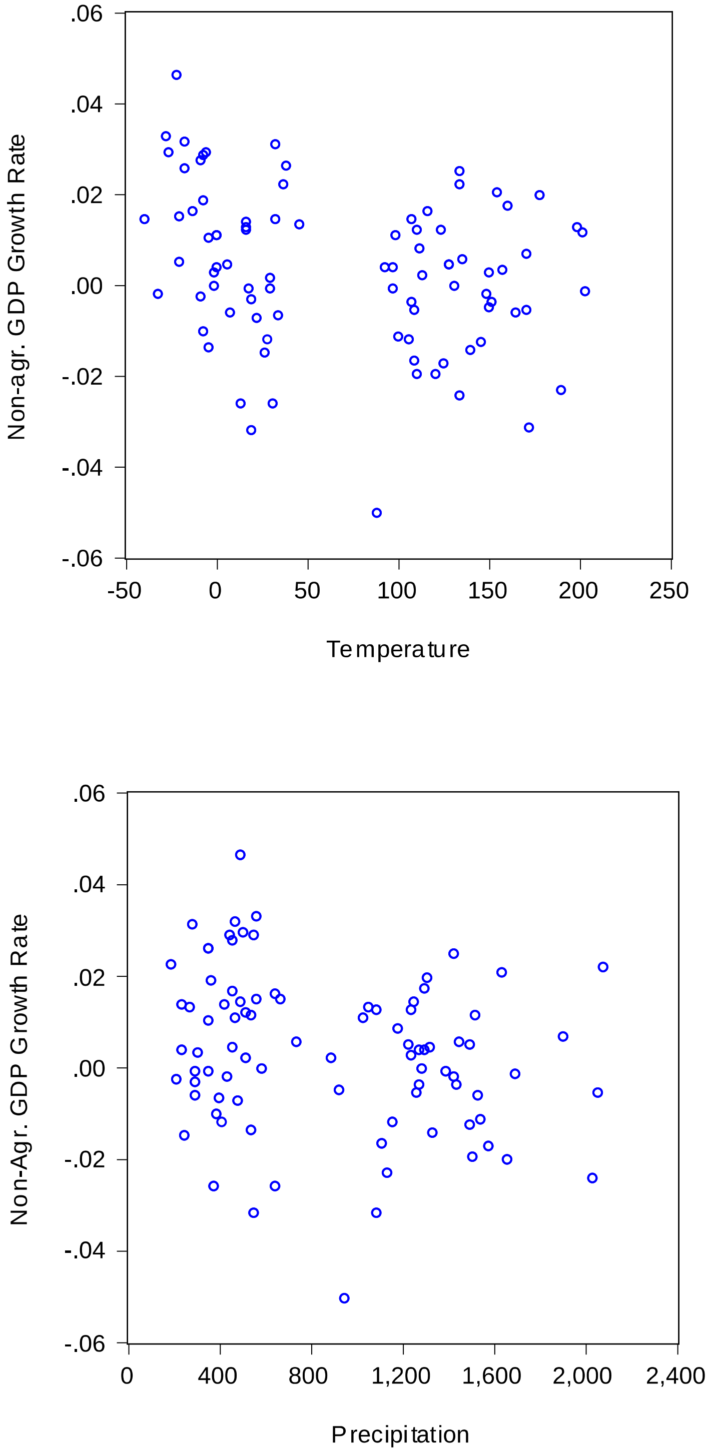
Figure 36: Scatterplot between Agricultural GDP Growth Rate with Population-weighted Temperature and Precipitation, 1986 Q1 – 2007 Q4





Data Source: The Conference Board of Canada (2015); Faramarzi et al. (2015)

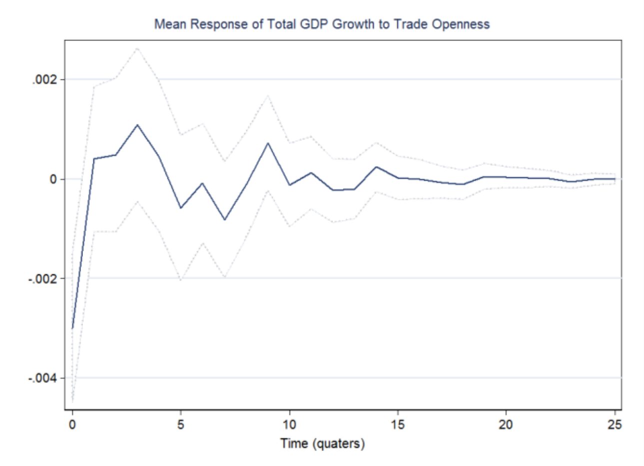
Figure 37: Scatterplot between Non-agricultural GDP Growth Rate with Population-weighted Temperature and Precipitation, 1986 Q1 – 2007 Q4

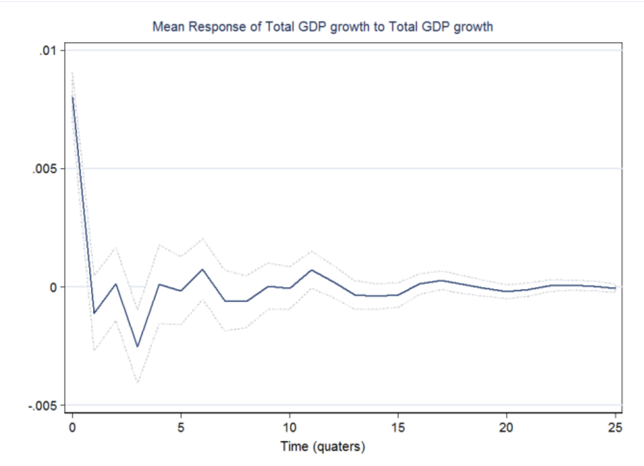


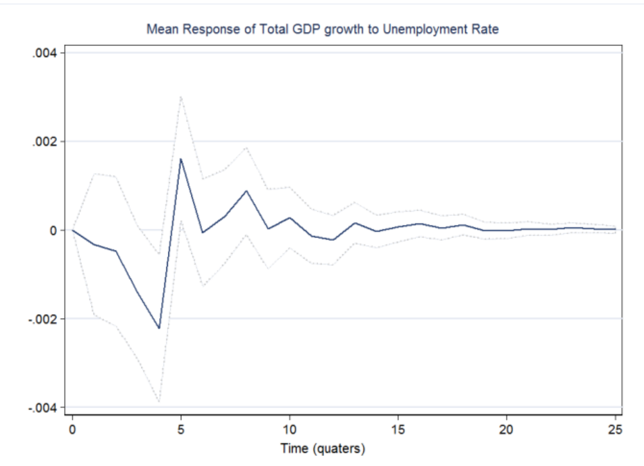
Data Source: The Conference Board of Canada (2015); Faramarzi et al. (2015)

Appendix E

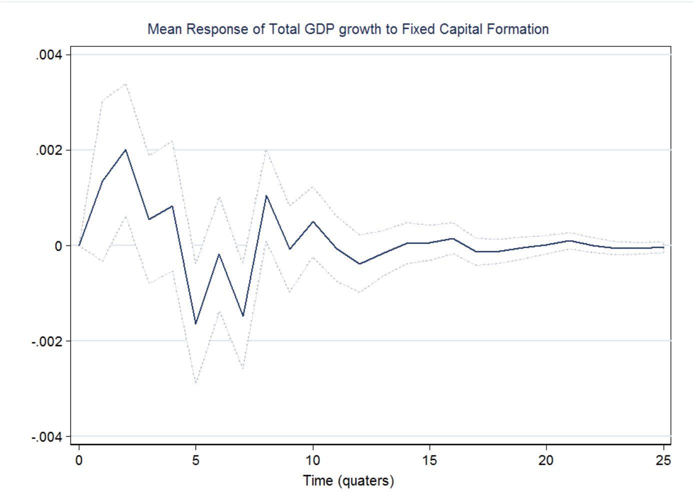
Figure 38: Impulse Response Functions[25] of VARX model (GDP Growth)



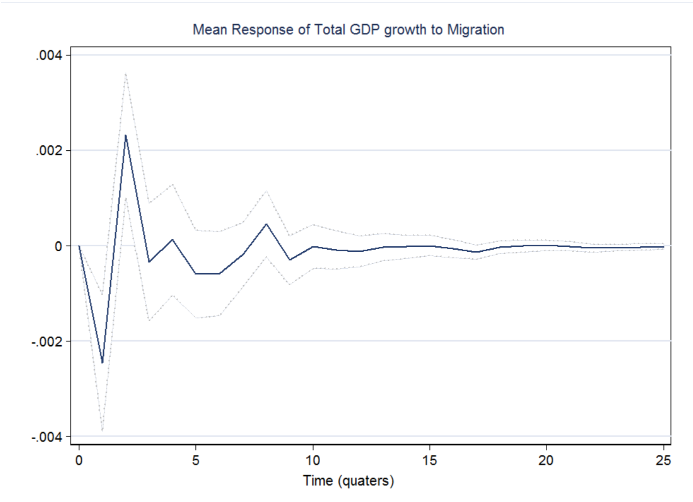




[25] The impulse response functions of total GDP growth/agricultural GDP growth/non-agricultural GDP growth (Figures 16 to 18) is based on the VARX model (see Equation 8). The impulse response functions define the response of three types of GDP growth from one-unit standard deviation increase in the endogenous variables over the time path.

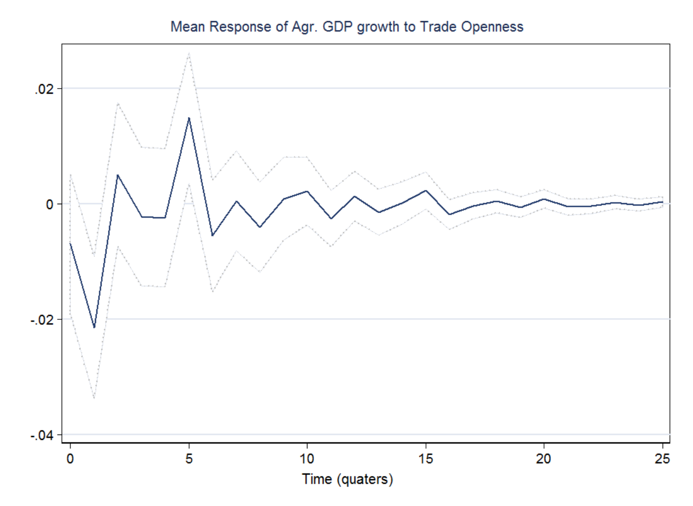


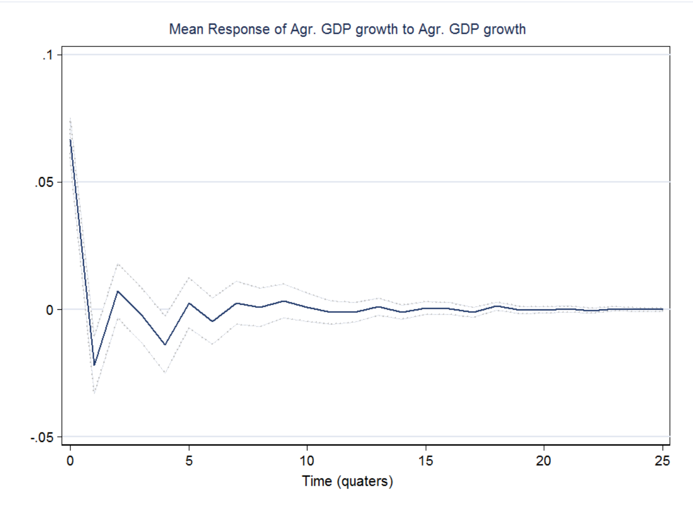
Mean Response of Total GDP growth to Fixed Capital Formation
.004
.002
0
-.002
-.004
0
5
10
15
20
25
Time (quaters)

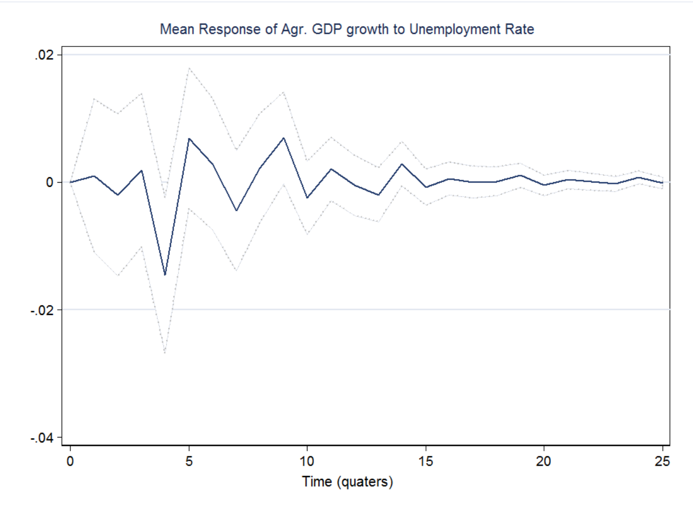


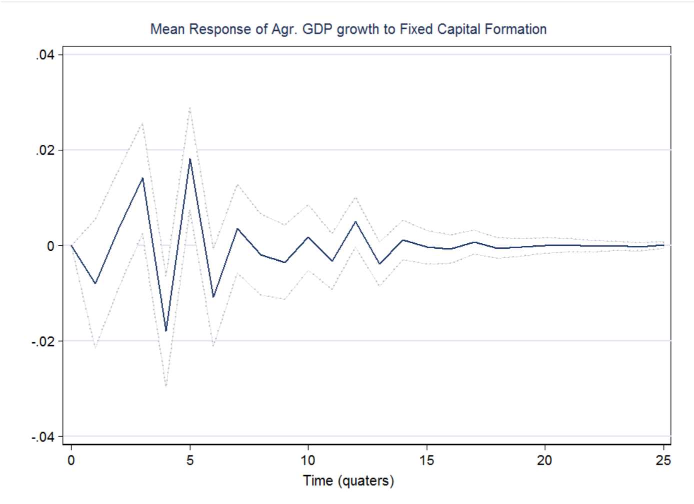
Mean Response of Total GDP growth to Migration
.004
.002
0
-.002
-.004
0
5
10
15
20
25
Time (quaters)

Figure 39: Impulse Response Functions of VARX model (Agr. GDP Growth)

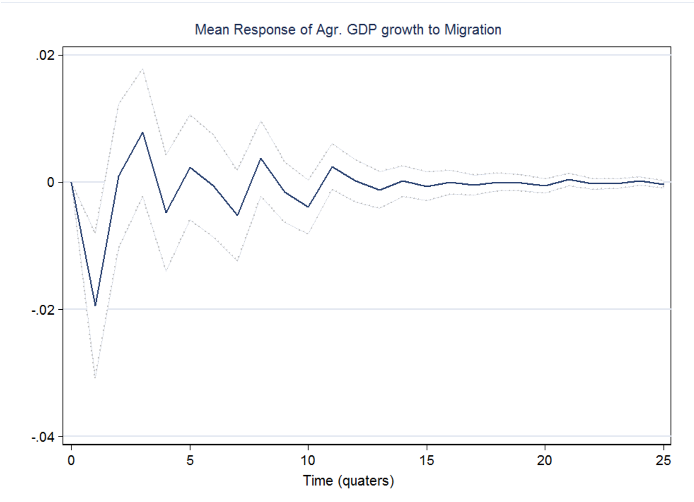






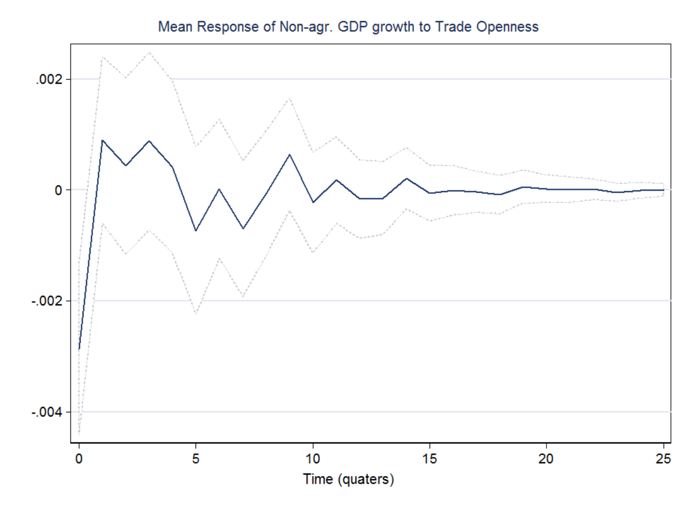


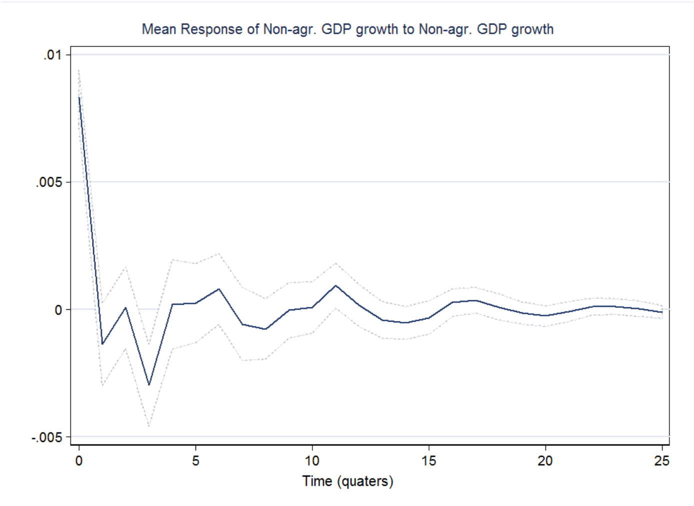
Mean Response of Agr. GDP growth to Fixed Capital Formation
.04
.02
0
-.02
-.04
0
5
10
15
20
25
Time (quaters)

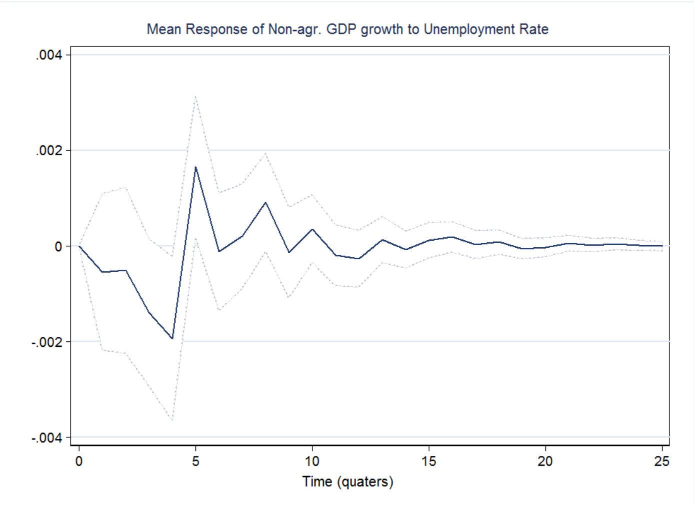


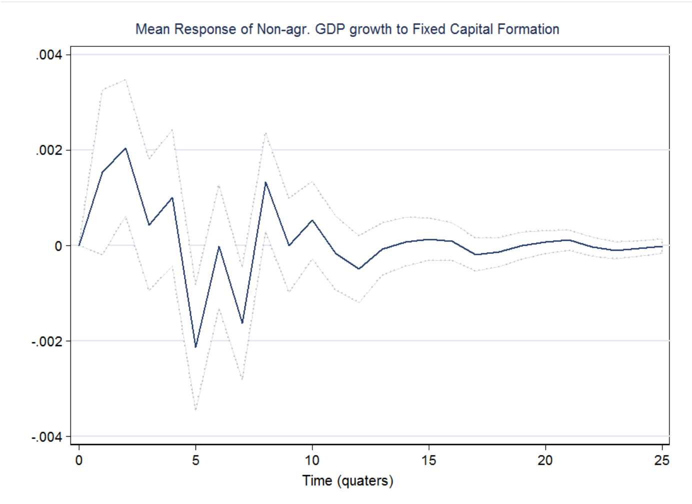
Mean Response of Agr. GDP growth to Migration
.02
0
-.02
-.04
0
5
10
15
20
25
Time (quaters)

Figure 40: Impulse Response Functions of VARX model (Non-agr. GDP Growth)

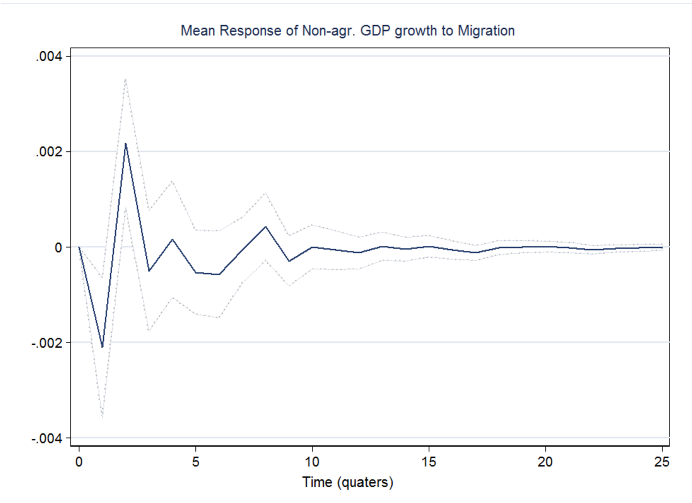








Mean Response of Non-agr. GDP growth to Fixed Capital Formation
.004
.002
0
-.002
-.004
0
5
10
15
20
25
Time (quaters)



Mean Response of Non-agr. GDP growth to Migration
.004
.002
0
-.002
-.004
0
5
10
15
20
25
Time (quaters)

Appendix F

1. STATA Code

Lag length selection:

```
varsoc gdp_capita_growth fixed_capital_growth migration unemployment_growth
trade_open_growth, maxlag(4) exog(Prec_P Max worldgdp_capita_growth oil_price_growth)

varsoc aggdp_capita_growth fixed_capital_growth migration unemployment_growth
trade_open_growth, maxlag(4) exog(Prec_P Max worldgdp_capita_growth oil_price_growth)

varsoc nonaggdp_capita_growth fixed_capital_growth migration unemployment_growth
trade_open_growth, maxlag(4) exog(Prec_P Max worldgdp_capita_growth oil_price_growth)
```

Running the VARX model:

```
var trade_openness_growth gdp_growth unemployment_growth fixed_capital_growth
migration_growth, lags(1/4) exog(real_oil_growth l1_real_oil_growth l2_real_oil_growth
l3_real_oil_growth l4_real_oil_growth    worldgdp_growth lag1_worldgdp_capita_growth
lag2_worldgdp_capita_growth lag3_worldgdp_capita_growth lag4_worldgdp_capita_growth Prec_P
l1_Prec_P l2_Prec_P l3_Prec_P l4_Prec_P Max l1_Max l2_Max l3_Max l4_Max)

var trade_openness_growth aggdp_growth unemployment_growth fixed_capital_growth
migration_growth, lags(1/4) exog(real_oil_growth l1_real_oil_growth l2_real_oil_growth
l3_real_oil_growth l4_real_oil_growth    worldgdp_growth lag1_worldgdp_capita_growth
lag2_worldgdp_capita_growth lag3_worldgdp_capita_growth lag4_worldgdp_capita_growth Prec_P
l1_Prec_P l2_Prec_P l3_Prec_P l4_Prec_P Max l1_Max l2_Max l3_Max l4_Max)

var trade_openness_growth nonaggdp_growth unemployment_growth fixed_capital_growth
migration_growth, lags(1/4) exog(real_oil_growth l1_real_oil_growth l2_real_oil_growth
l3_real_oil_growth l4_real_oil_growth    worldgdp_growth lag1_worldgdp_capita_growth
lag2_worldgdp_capita_growth lag3_worldgdp_capita_growth lag4_worldgdp_capita_growth Prec_P
l1_Prec_P l2_Prec_P l3_Prec_P l4_Prec_P Max l1_Max l2_Max l3_Max l4_Max)
```

Create IRFs:

```
irf set, clear

irf set "/Users/myxxxyyy/Desktop/var_1_model_dif.irf", replace

irf creat gdpirf, step(24)
```

2. MATLAB code[26]

The following program "apply_AgGDP.m" is to derive the OLS estimates of the mean response of agricultural GDP growth to the exogenous variables.

```
close all

clear all;

tic;

% Set parameter values

monte = 3000;                                        % # of repetitions in the Monte Carlo loop

st = 24;                                              % # of periods for the forecast

dep = 'Mean Response of Agr. GDP growth to';      % the title for drawing figures

p = 4;    q = 4;                % VARX(p,q)

% Load data

vars = xlsread('AgGDP_4lags.xlsx');

vars = vars(109:188,:);

[nobs,col] = size(vars);    % nobs = # of used observations\

%% Set model configuration

K = 5;            % # of endogenous vars

dis = 4;        % # of exogenous vars

Y = vars(:,1:5);

LYs = vars(:,6:25);
```

[26] Our MATLAB code was adapted from Fomby, Ikeda and Loayza (2013). See MATLAB code in Appendix F.

```
nv = K*p + dis*(q+1);    % # of explanatory variables per equation

RH = [LYs Xs];    % Stacked right-hand-side vars

% Demean the series

dmLYs=zscore(LYs);

dmY=zscore(Y);

dmXs=zscore(Xs);

dmRH = [dmLYs dmXs]; % Demeaned tacked right-hand-side vars

%% Oridnary Least Square

deltahat = inv(dmRH'*dmRH)*dmRH'*dmY;

% Matrix inv(Q)

iQ = inv((dmRH'*dmRH)/nobs);

% Estimated variance covariance matrix

eps = zeros(nobs,K);

eps = dmY - dmRH*deltahat;

omega = (eps'*eps)/nobs;

detomega = det((eps'*eps)/(nobs));

% Calculate AIC and SBC

% (nv = # of coefficients per equation)

% Information Criteria

like = -(nobs/2)*(K*(1+log(2*pi))+log(detomega));
```

```
% k = nen*pa (k = total # of parameters)

AIC = -2*(like/nobs) + 2*(K*nv/nobs);

SBC = -2*(like/nobs) + (K*nv)*log(nobs)/nobs;

% disp(AIC);

% disp(SBC);

% Calculate matrix psi from deltahat

psi = psimat4(p,q,K,dis,st,deltahat);

% Set up phi matrix

phi = zeros(K*p,K);

for i = 1:p;

    phi(1+K*(i-1):K*i,:) = deltahat(1+K*(i-1):K*i,:)';

end;

% Set up theta matrix

theta = zeros(K*(q+1),dis);

for i = 1:q+1;

    theta(1+(i-1)*K:K*i,:) = deltahat(1+K*p+dis*(i-1):K*p+dis*i,:)';

end;

%    Store mean responses

mr = zeros(st+1,dis);

for i = 1:st+1
```

```
        mr(i,:) = psi(K*i,:);    % Store only the effects on growth (the last one of end vars)
end;
% Vectorize psi matrix
vecpsi = zeros(K*dis*(st+1),1);
for i = 1:st+1;
    vecpsi(1+(i-1)*K*dis:K*dis*i) = reshape(psi(1+K*(i-1):K*i,:)',K*dis,1);
end;
% Set up Pi matrix (Hamilton 11.1.6)
piprime = zeros(K,K*p+dis*(q+1));
for i = 1:p;
    piprime(:,1+(i-1)*K:K*i) = phi(1+(i-1)*K:K*i,:);
end;
for i = 1:q+1;
    piprime(:,(K*p)+1+(i-1)*dis:(K*p)+i*dis) = theta(1+(i-1)*K:K*i,:);
end;
pimat = piprime';
smpi = reshape(pimat,K*(K*p+dis*(q+1)),1);    % small pi (vector)
% Monte Carlo loop
mr_rnd = zeros((st+1)*dis,monte);
ce = zeros(dis,monte);    % Cumulative effects
```

```
for num = 1:monte;    % 'monte' times of iterations

    smpi_rnd = mvnrnd(smpi,kron(omega,iQ)/nobs);

    pi_rnd = reshape(smpi_rnd,K*p+dis*(q+1),K);

    psi_rnd = psimat4(p,q,K,dis,st,pi_rnd);

    % Store mean responses

    for i = 1:dis

        for j = 1:st+1

            mr_rnd(j+(i-1)*(st+1),num) = psi_rnd(K*j,i);

        end;

    end;

    % Store cumulative effects

    for i = 1:dis

        ce(i,num) = sum(mr_rnd(1+(i-1)*(st+1):4+(i-1)*(st+1),num));

    end;

end;    % End of Monte Carlo loop

upper95 = round(monte*0.95); lower5 = round(monte*0.05);

upper90 = round(monte*0.9); lower10 = round(monte*0.1);

mr_sort = sort(mr_rnd,2);

ce_sort = sort(ce,2);
```

```
mr_low5 = reshape(mr_sort(:,lower5),st+1,dis);

mr_low10 = reshape(mr_sort(:,lower10),st+1,dis);

mr_up90 = reshape(mr_sort(:,upper90),st+1,dis);

mr_up95 = reshape(mr_sort(:,upper95),st+1,dis);

ce_sum = [ce_sort(:,lower5) ce_sort(:,lower10) mean(ce_sort,2) ce_sort(:,upper90)
ce_sort(:,upper95)];

for j = 1:4;

        disp('______');

    for i = 1:12;

        if mr_up90(i,j) > 0 & mr_low10(i,j) > 0 & mr_low5(i,j) < 0

            disp(' *');

        elseif mr_up95(i,j) > 0 & mr_low5(i,j) > 0

            disp('**');

        elseif    mr_up90(i,j) < 0 & mr_low10(i,j) < 0 & mr_up95(i,j) > 0

            disp(' *');

        elseif mr_up95(i,j) < 0 & mr_low5(i,j) < 0

            disp('**');

        elseif mr(i,j) > 0

            disp('    ');

        else
```

```
            disp('    ');
        end;
    end;
    if ce_sum(j,2) > 0 & ce_sum(j,4) > 0 & ce_sum(j,1) < 0
        disp(' *');
    elseif ce_sum(j,1) > 0 & ce_sum(j,5) > 0
        disp('**');
    elseif ce_sum(j,2) < 0 & ce_sum(j,4) < 0 & ce_sum(j,5) > 0
        disp(' *');
    elseif ce_sum(j,1) < 0 & ce_sum(j,5) < 0
        disp('**');
    elseif ce(j,3) > 0;
        disp('    ');
    else
        disp('    ');
    end;
end;
disp('______');
% Draw the graphs
```

```
x = (0:1:st)'; y = zeros(st+1,1);

figure;

plot(x,mr(:,1),'-b',x,mr_up90(:,1),':b',x,mr_low10(:,1),':b',x,y,'-k');

xlabel('Time (quarters)');

title([dep ' Oil Price ']);

figure;

plot(x,mr(:,2),'-b',x,mr_up90(:,2),':b',x,mr_low10(:,2),':b',x,y,'-k');

xlabel('Time (quarters)');

title([dep ' World GDP per Capita ']);

figure;

plot(x,mr(:,3),'-b',x,mr_up90(:,3),':b',x,mr_low10(:,3),':b',x,y,'-k');

xlabel('Time (quarters)');

title([dep ' Precipitation ']);

figure;

plot(x,mr(:,4),'-b',x,mr_up90(:,4),':b',x,mr_low10(:,4),':b',x,y,'-k');

xlabel('Time (quarters)');

title([dep ' Average Maximum Temperature ']);

toc;

disp(toc/60);
```

The following function “psimat4.m” is to calculate matrix psi from phi and theta in above program “apply_AgGDP.m”

```
function psi = psimat4(p,q,nen,dis,st,beta)

% st: period of forecast

% nen: K

% beta: deltahat

% Set up phi matrix

phi = zeros(nen*p,nen);

for i = 1:p;

    phi(1+nen*(i-1):nen*i,:) = beta(1+nen*(i-1):nen*i,:)';

end;

phi1 = phi(1:nen,:);

phi2 = phi(1+nen:2*nen,:); phi3 = phi(1+2*nen:3*nen,:);

phi4 = phi(1+3*nen:4*nen,:); phi5 = zeros(nen,nen);

% Set up theta matrix

theta = zeros(nen*(q+1),dis);

for i = 1:q+1;

    theta(1+(i-1)*nen:nen*i,:) = beta(1+nen*p+dis*(i-1):nen*p+dis*i,:)';

end;

theta0 = theta(1:nen,:); theta1 = theta(1+nen:2*nen,:);
```

```
theta2 = theta(1+2*nen:3*nen,:); theta3 = theta(1+3*nen:4*nen,:);

theta4 = theta(1+4*nen:5*nen,:); theta5 = zeros(nen,dis);

% Calculate psi matrix

psi = zeros(nen*(st+1),dis);

psi(1:nen,:) = theta0;    % psi0 = theta0

psi(1+nen:2*nen,:) = theta1 + phi1*psi(1:nen,:);    % psi1 =    theta1 + phi1*psi0

psi(1+2*nen:3*nen,:) = theta2 + phi1*psi(1+nen:2*nen,:) + phi2*psi(1:nen,:);    % psi2 =
theta2 + phi1*psi1 + phi2*psi0

psi(1+3*nen:4*nen,:) = theta3 + phi1*psi(1+2*nen:3*nen,:) + phi2*psi(1+nen:2*nen,:) +
phi3*psi(1:nen,:);    % psi3 = theta3+phi1*psi2+phi2*psi1+phi3*psi0

psi(1+4*nen:5*nen,:) = theta4 + phi1*psi(1+3*nen:4*nen,:) + phi2*psi(1+2*nen:3*nen,:) +
phi3*psi(1+nen:2*nen,:)+phi4*psi(1:nen,:);    % psi4 =
theta4+phi1*psi3+phi2*psi2+phi3*psi1+psi4*psi0

psi(1+5*nen:6*nen,:) = theta5 + phi1*psi(1+4*nen:5*nen,:) + phi2*psi(1+3*nen:4*nen,:) +
phi3*psi(1+2*nen:3*nen,:)+phi4*psi(1+nen:2*nen,:)+phi5*psi(1:nen,:);

for i = 6:st;

    psi(1+nen*i:nen*(i+1),:) = phi1*psi(1+nen*(i-1):nen*i,:)+ ...

                                        phi2*psi(1+nen*(i-2):nen*(i-1),:) + ...

                                        phi3*psi(1+nen*(i-3):nen*(i-2),:) +
phi4*psi(1+nen*(i-4):nen*(i-3),:) + phi5*psi(1+nen*(i-5):nen*(i-4),:);

end;
```