International Journal of Energy Economics and Policy
Vol. 4, No. 2, 2014, pp.178-188
ISSN: 2146-4553
www.econjournals.com

Energy Use, Income and Carbon Dioxide Emissions: Direct and Multi-Horizon Causality in Canada

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ABSTRACT: This paper explores the causal relationship between energy, emissions and income in Canada for the period 1960- 2005. This study explores these relationships using the Toda Yamamoto approach in a multivariate framework including labour and capital as auxiliary variables. We also test the hypothesis of indirect or multi-horizon Granger non-causality between these variables, since causal effects may occur more than one-period-ahead, as is assumed by the standard Granger non-causality test. We find that there is bi-directional direct causality between income and energy use in Canada, and no other channels of causality between the three variables. However, indirect Granger non-causality testing shows that there is bi-directional causality between all variables in the system. This result is contrary to other results in the literature, and has different implications for energy and environmental policy.

Keywords: Energy use; Greenhouse gas emissions; Multi-horizon Granger causality; Canada.
JEL Classifications: C12; C22; Q48; Q53

1. Introduction

Energy policy has always been of paramount importance in national and international affairs. The negative impact of the oil crises in the 1970s has led countries to reduce reliance on fossil fuels (i.e. energy use), in order to protect against future potential supply shortages or shocks. Further, due to the potential impacts of greenhouse gas induced global warming; there is an additional need to reduce fossil fuel use and greenhouse gas emissions in many developed countries. Understanding the causal relationship between energy and income has been the focus of a great deal of literature, as the results can be used to inform national energy policy. If energy use is shown to have a causal effect on income, reduced energy use due to supply shocks or conservation measures will reduce future economic growth. In such a case, policymakers should invest in alternative technologies that promote cleaner forms of energy use in order to reduce reliance on fossil fuels, as well as greenhouse gas emissions.

The casual relationship between income and emissions has been examined in recent studies, as this relationship also has important implications for policies aimed at reducing energy use and emissions. If income causes emissions, then countries must reduce income in the short run in order to achieve emissions reductions. If, however, there is an inverted U shaped curve, as assumed in the Environmental Kuznets Curve literature, countries may be able to grow out of their emissions problems in the long run. In the meantime, cleaner energy technologies may be adopted to reduce current emissions. However, the results of causality tests can reveal complications with this policy prescription; a feedback effect from emissions to income implies that countries may not be able to grow out of their emissions problems, since the growth of economic output and emissions are linked in more complicated ways. In such a case, policy makers will necessarily face trade-offs between income growth, energy use and greenhouse gas emissions.

This paper tests the hypothesis of Granger causality between energy use, income and carbon dioxide (CO_2) emissions in Canada using a multivariate framework, with the goal of informing energy and environmental policy. There are two novel contributions of the paper. First, it is the only study to look at the causal relationship between aggregate energy use, income and emissions in Canada in the same framework, including labour and capital as auxiliary variables. Recent studies argue that these related variables should be analyzed in the same framework, to avoid model misspecification and to capture the interrelated policy implications discussed above (Ang, 2007). Further, Lutkepohl (1993) and Stern (1993, 2000) demonstrated the need to include auxiliary variables in the model to avoid omitted variable bias, and including auxiliary variables allows for channels of causation through other variables (i.e., energy is necessary for labour and capital, which impact income). Second and related to the last point, we employ the relatively new econometric method of indirect or multi-horizon causality testing (Dufour et al., 1998, 2006). While recent studies that use a multivariate framework account for causation that can occur through other variables in the system, these studies only account for one-period ahead, or direct Granger causality. However, in a multivariate setting, causality may arise indirectly at longer horizons, via one or more auxiliary variables in the system. We focus primarily on the policy implications related to the emissions- income nexus in this study, since this has received less attention in the literature and results to date have been mixed.

Direct, one-period-ahead Granger causality tests in this study confirm the results of other studies in Canada, who find bi-directional causality between energy and income. Further, the results are similar to those by Soytas et al. (2007) in the US, who find that there is no direct causal relationship running from income to emissions. However, based on indirect causality tests, bi-directional causality is found between all variables at various horizons. This contradicts the results by Day and Grafton (2003) and Hamit-Haggar (2012) for income-emissions in Canada. The results of this study add new insight regarding the potential impact of policy related to energy and the environment in Canada, and add a novel result to the literature.

This paper proceeds as follows. Section two reviews the relevant bodies of literature. Section three presents the methods used in this paper and section four discusses the data and empirical results. Section five presents conclusions and policy implications of this work.

2. Literature Review

A broad overview of Granger causality studies between income and energy and income and emissions is provided, with particular focus on a few relevant studies. We conclude by elaborating on the contributions of the current study, in light of limitations in the literature.

Pioneering work by Kraft and Kraft (1978) tested for causality between income and energy use in the US, following Granger (1969). Using data from 1947 to 1974, causality was found to run from GDP to energy. Many other studies have supported this same result in the US (Akarca and Long, 1979), Australia (Narayan and Smyth, 2005), South Korea (Yu and Choi, 1985), industrialized countries (Erol and Yu, 1987a,b), Pakistan and Indonesia (Masih and Masih, 1996), six Gulf Cooperation Council countries (Al-Iriani, 2006), Bangladesh (Mozumder and Marathe, 2007), and various oil exporting countries (Mehrara, 2007). In other studies, causality was found to run from energy use to GDP, including in the Philippines (Yu and Choi, 1985), India (Masih and Masih, 1996), Shanghai (Wolde-Rufael, 2004), Sri Lanka (Morimoto and Hope, 2004), ten Asian newly industrialized countries (Chen, Kuo and Chen, 2007) and Indonesia (Asafu-Adjaye, 2000). The literature has also found bidirectional causality between energy use and GDP in the US (Stern, 1993, 2000), Taiwan (Yang, 2000), Korea and Taiwan (Masih and Masih, 1997), Argentina (Soytas and Sari, 2003), Canada (Ghali and El-Sakka, 2004), Korea (Yoo, 2005), various African countries (Wolde-Rufael, 2006) and Thailand and the Philippines (Asafu-Adjaye, 2000). Also, cases of non-causality were found in the US by Erol and Yu ((1987a, b); (1989)) and Asafu-Adjaye (2000). A detailed literature survey on energy-growth nexus is given in the study of Ozturk (2010).

Recent Canadian studies include Ghali and El-Sakka (2004), Soytas and Sari (2006) and Salamaliki and Venetis (2013), each of whom found bi-directional causality between energy and income. Ghali and El-Sakka use a multivariate VECM framework based on the neo-classical one-sector aggregate production technology where capital, labour, and energy are treated as separate inputs. Salamaliki and Venetis (2013) use the same framework, but also test for multi-horizon causality between energy and income in G7 countries. This is the only other study to consider indirect causation in this literature, and they find bi-directional causality between income and energy use at various horizons.

In regards to the income-emissions literature, we focus on recent Granger causality studies, and do not discuss the many empirical tests of the EKC hypothesis. Surveys of the EKC literature can be found in Stern (2004), Dinda (2004), Acaravci and Ozturk (2010), Shahbaz et al. (2013). Studies in the EKC literature often look at the effect of income on emissions, ignoring the potential feedback effect from emission to income. Granger causality tests explicitly test for such a feedback effect, and the existence of these effects may have important policy implications, as discussed above.

Coondoo and Dinda (2002) and Dinda and Coondoo (2006) test for Granger causality between income and carbon dioxide emissions in groups of countries using panel data in a bivariate framework and find that there is bidirectional causality between emissions and income for North America. Ang (2007) argues that energy, emissions and income are linked together and that one should estimate causality between the three variables in one framework, to avoid any potential misspecification. Ang uses data from France from 1960 to 2000, estimates a model including income, energy, emissions and emissions squared, and finds that there is unidirectional causality running from output growth to energy and emissions. Soytas et al. (2007) also estimate the causal relationship between energy, emissions and income in the US from 1964-2004 in the same model. They use the Toda and Yamamoto (TY) (1995) approach to show that there is causality running from energy to emissions in the US, but no other causality between income, emissions and energy. Ozturk and Uddin (2012) investigate the long-run Granger causality relationship between energy consumption, carbon dioxide emission and economic growth in India over the period 1971-2007. The augmented Dickey–Fuller test (ADF), Phillips-Perron test (PP) and KPSS test are used to test for Granger causality in cointegration models which take account of the stochastic properties of the variables. The most important result is that there is feedback causal relationship between energy consumption and economic growth in India. Also, there is causal relationship from energy consumption to carbon emission in the case of India. Farhani and Ben Rejeb (2012) applied the panel unit root tests, panel cointegration methods and panel causality test to investigate the relationship between EC, GDP and CO_2 emissions for 15 MENA countries covering the annual period 1973-2008. The finding of this study reveals that there is no causal link between GDP and EC; and between CO_2 emissions and EC in the short run. However, in the long run, there is a unidirectional causality running from GDP and CO_2 emissions to EC.

In the Canadian context, Day and Grafton (2003) estimate the effect of income on four types of emissions for the period 1957 to 1997. Using the TY approach in a bivariate model, they determined that there was bi-directional causality between income and emissions in most cases. However, for CO_2, only unidirectional causality was found to run from income to emissions. Hamit-Haggar (2012) examine causality between energy, emissions and income in Canada, using a panel data approach for key Canadian industrial sectors from 1990-2007. Evidence of short run unidirectional causality is found to run from energy to emissions, from income to emissions, and from emissions to energy. While recent studies have explored the relationship between aggregate energy, income and emissions in the same model in different countries (Ang, 2007, Soytas et al., 2007), this has not been done in Canada. Finally, multi-horizon causality testing has not been explored in this literature.

There is no consensus in the energy-income or emissions-income Granger causality literature, due in part to the fact that results vary by country and in different time periods, due to the different economic and energy structures. However, part of the discrepancy in the literature is due to methodological issues. The time series properties of the data were not considered in earlier work, often producing spurious results. Also, many earlier studies test for causality in a bivariate framework. This framework is convenient, since non-causality one-period-ahead in a bivariate framework implies non-causality multiple periods ahead. However, studies in the last decade or so have adopted a multivariate framework, including different auxiliary variables (typically labour and capital) to account for potential omitted variable bias that occurs in the bivariate framework. Another limitation of this literature is that while the multivariate studies to date are able to pick up causation from one variable to another via an auxiliary variable, the tests, by design, examine one-period-ahead Granger causality. As Salamaliki and Venetis (2013) point out, one-period-ahead non-causality in a multivariate framework does not imply non-causality multiple periods ahead. Multi-horizon (indirect) Granger causality testing is required to uncover all channels of causation in a multivariate framework.

The current study will address these limitations in several ways. First, we avoid potential bias by testing for causality between energy, income and emissions in Canada in a single multivariate framework, including labour and capital. We also use time series analysis and the relatively recent TY approach to test for Granger causality. Third, this study will also test for multi-horizon Granger causality between these variables, following the methodology of Dufour et al. (1998, 2006). Salamaliki and Venetis (2013) are the only other authors to consider this technique in this literature, but they do not explore the relationship between income and emissions. Therefore, the main contributions of this paper are the policy implications based on the results of the income-emissions causality testing. Relatively little work has been done in this area, and the indirect causality tests of Dufour et al. (1998, 2006) may uncover channels of causation that are not found in direct causality tests in the income-emissions nexus. Nonetheless, it is important to consider energy, emissions and income together in the same framework to avoid misspecification and examine all policy implications of these related variables.

3. Methodology

3.1 Unit root testing

The TY approach used in this study requires information about the highest order of integration among all variables. We first test for the highest order of integration using Augmented Dickey Fuller (1979) (ADF), Phillips and Perron (1988), Elliott et al. (1996), Dickey–Fuller GLS detrended (DF–GLS) and Point Optimal, Ng and Perron's (2001) MZα (NP) and Kwiathowski et al. (1992) (KPSS) unit root tests. The first four tests assume the null hypothesis of a unit root in the data, whereas KPSS tests the null hypothesis of stationary data. In each situation, we assume a constant and trend; since all of the data series exhibit upward trends, we allow for a deterministic trend in the data.

3.2 Specifying a model and direct Granger causality testing

We then estimate the following unrestricted level VAR:

$$y_t = u + \delta t + \sum_{l=1}^{p} \phi_l y_{t-l} + et \qquad (1)$$

Where y_t is a vector representing income, energy use, carbon dioxide emissions, labour and capital stock; p is the lag length; and $ø_l$ is a k×k parameter matrix with $(i,j)^{th}$ element $ø_{ij,l}$ that provides the (partial) impact of $y_{j,t-l}$ *on* y_{it}. After testing for the optimal number of lags, we test for dynamic and structural stability, serial independence and normality of the error term.

When data are cointegrated and non-stationary, Granger causality can be tested in either a VAR model, using stationary (first differenced) data, or a VEC model. The TY approach, however, allows us to estimate a VAR model using level data, and test for Granger causality regardless of cointegration and integration of variables. However, since the presence of cointegration supports the finding of a causal relationship in the data (which can be used to verify the results of Granger causality tests), we test for cointegration as a robustness check, based on the Johansen (1988) and Johansen and Juselieus (1992) procedure. We use this procedure since the Engle-Granger (1987) method does not identify the number of cointegrating vectors, and results differ depending on which variable is chosen as the dependent variable in the regression.

We then use the VAR to test for Granger causality. A variable Y is said to be Granger non-causal for X if knowledge of Y at past values does not help to predict X any better than if we just had past values for X. We use a VAR and the following TY approach to test for causality. Upon determining the appropriate lag length (p), one should include as exogenous variables d additional lags of each variable, where d is the maximum order of integration in any of the variables. Testing the joint significance of the first p coefficients will provide a Wald test that is asymptotically chi-squared distributed.

3.3 Indirect causality testing

It has been noted (Lutkepohl, 1993; Dufour and Renault, 1998; Giles, 2002) that for multivariate models where a vector of auxiliary variables Z is used in addition to the variables of interest X and Y, it is possible that Y does not cause X in the traditional sense, as above, but can still help to predict X several periods ahead. This is due to the fact that Y may help to predict Z one-period-ahead, which in turn has an effect on X at later periods. Studying these indirect effects may impact the literature significantly; one may be able to identify causal relationships that otherwise did not 'exist', as they took longer than one period to materialize.

Dufour et al. (2006) propose methods for estimating these indirect effects that only require linear regression techniques as well as asymptotic distributional theory. We follow Clarke and Ralhan (2005), who present the model of Dufour et al. (2006), and write the VAR model in equation (1) h horizons ahead and test for Granger causality at each of the h periods. The VAR one-period-ahead, at time t+1, denoted as a horizon-1 autoregression, are written as:

$$y_{t+1} = u^* + \delta^*(t+1) + \sum_{l=1}^{p} \phi_l y_{t+1-l} + e_{t+1} \qquad (2)$$

Horizon-1 Granger causality from y_j to y_i occurs when $ø_{ij,l} \neq 0$ for at least one l =1,...,p. This leads to the usual null hypothesis, for horizon-1 Granger causality, Ho : $ø_{ij}=0$ for all coefficients (1,…, p). This hypothesis can be tested using a Wald test of the form used by TY.

Again based on Dufour et al. (2006), one can write a horizon-2 autoregression, t+2 periods ahead as: $y_{t+2} = u^* + \delta^*(t+2) + \sum_{l=1}^{p} \phi_l y_{t+2-l} + e_{t+2}$ (3)
upon substitution of equation (2) into equation (3), Granger causality testing from the resulting VAR leads to testing zero restrictions on nonlinear hypotheses of the coefficients.[1] To simply matters, Dufour et al. (2006) propose a linear VAR to estimate in this instance:

$$y_{t+2} = \bar{u} + \bar{\delta}t + \sum_{l=1}^{p} \phi_l y_{t+1-l} + e_{t+2} + \emptyset_1 e_{t+1} \quad (4)$$

where $ø_l$ is a k×k parameter matrix with $(i,j)^{th}$ element $ø_{ij,l}$ that provides the (partial) impact of $y_{j,t+1-l}$ on $y_{i,t+2}$. The null hypothesis that $ø_{ij} = 0$, (1,…, p) can be tested using the TY approach, with the interpretation as usual: if one of the $ø_{ij}$ do not equal 0, then we can reject the null that Y_j does not Granger cause Y_i (at the t+2 horizon).

Finally, based on the same approach, an h-horizon autoregression can be written as:

$$y_{t+h} = u^* + \delta^*(t+h) + \sum_{l=1}^{p} \phi_l y_{t+h-l} + e_{t+h} \quad (5)$$

And can be estimated using an unrestricted linear VAR as follows, with the same TY approach used to estimate whether $Y_{j,\,t+1-l}$ has a causal effect on Y_i, h periods ahead:

$$y_{t+h} = \overline{u_h} + \overline{\delta_h}t + \sum_{l=1}^{p} \phi_{h,l} y_{t+1-l} + \sum_{k=0}^{h-1} \varphi_k e_{t+h-k} \quad (6)$$

where $ø_{h,l}$ is a k×k parameter matrix with $(i,j)^{th}$ element $ø_{ij,h,l}$ that provides the (partial) impact of $y_{j,t+1-l}$ on $y_{i,t+h}$.

There are some potential issues with applying this technique in practice. By using a linear model to approximate non-linear equations, some information will be ignored, leading to a likely loss in power and efficiency. However, Dufour et al. (2006) demonstrate that the test statistic for the TY approach in the h-period autoregression will be asymptotically chi-squared distributed. Further, one can see from Equation (6) that the error term will follow a moving average process. Thus, we follow the suggestion from Dufour et al. (2006) that one estimate Equation (6) using a seemingly unrelated regression estimator (SUR) with a heteroskedastic-autocorrelation consistent (HAC) estimator of its variance-covariance matrix, and then employ the TY approach.

4. Data and Results

4.1 Data and Unit Root tests

We use the following annual time series data for Canada for the period 1960 to 2005:
L: Labour force, units
E: Aggregate energy use in Kt Oil Equivalent
CO: Carbon dioxide emissions, in Kt
Y: Real GDP, in $
K: Gross fixed capital formation, in $

All data came from the World Development Indicators database for the entire period, with the exception of L, which came from Statistics Canada Historical Statistics for the period 1960-1980. The natural log of each of these variables was used, since an exponential trend was apparent in some of the variables. Each of the variables does exhibit a distinct upward linear trend, so, for the purpose of testing and model building, specifications will include a constant and a linear trend, to allow for the possibility that there is a deterministic trend in the model. Note that we use gross fixed capital formation since capital stock data are not available; this is typically done in the literature, as formation is believed to be a reliable proxy for changes in capital stock. Table 1 provides the results for unit root tests conducted in this study.

In all cases using the ADF test, the null hypothesis of a unit root in the levels is not rejected, and the null of a unit root in the first differenced data is rejected, at 5% significance. Using the KPSS test, the null of stationarity in the levels is rejected in all variables. However, unlike the ADF test, the null of stationarity in the first differences is also rejected for some variables. Emissions and energy are I(2) at 5% significance and labour and income are I(2) at 10%. However, results of the PP, ADF-GLS and Ng tests all confirm the results of the ADF test that each variable is I(1). Since the results of most

[1] See Clarke and Ralhan (2005) for more detail regarding this non-linear specification.

tests indicate that the data are I(), and this confirms results from previous studies in this region (Ghali and El-Sakka, 2004), we proceed under the assumption that all variables are I(1). Granger causality tests will be applied with maximum order of integration (d) equal to 1. However, since the TY approach is sensitive to maximum order of integration, we also run the Granger causality tests using a VAR with maximum order of integration equal to 2, and discuss how the results are impacted.

Table 1. Unit root tests

	ADF (t-stat)	*KPSS (LM stat)*	*PP (t-stat)*	*ADF GLS (ERS) (t-stat)*	*Ng Peron*
	Levels				
Y	-3.05	0.19*	-2.36	-1.63	-3.87
E	-2.90	0.19*	-2.43	-1.36	-3.09
K	-2.96	0.15*	-2.19	-1.77	-5.09
L	-0.77	0.21*	-0.41	-1.49	-10.61
CO	-2.33	0.16*	-2.35	-1.29	-1.79
	First Difference				
Y	-4.40*	0.12**	-4.88*	-4.79*	-19.81*
E	-4.54*	0.17*	-4.49*	-4.50*	-19.03*
K	-4.93*	0.08	-4.94*	-4.79*	-19.85*
L	-3.58*	0.11**	-3.52*	-3.29*	-13.59
CO	-6.31*	0.17*	-6.37*	-6.12*	-21.72*
* significance at the 5% level; ** significance at the 10% level					

4.2 Model and cointegration testing

This paper estimates the unrestricted VAR in Equation (6) using the vector of variables {Y, E, L, K , CO}. Lag selection criteria and diagnostics tests are used to determine the appropriate model to be used for Granger causality testing. The lag length should be long enough that the errors are independent and identically distributed, but short enough to allow estimation (Ghali and El-Sakka, 2004). The Schwarz Information Criterion (SIC) criteria show that 1 lag is optimal, however, at that lag length, serial correlation is present. We therefore estimate a VAR (1) and add lags until the VAR does not show signs of serial correlation. This occurs with 4 lags of each variable. Table 2 reports diagnostics tests of the VAR (4) model. The adjusted R squared is high and the errors are serially independent, based on the Breusch-Godfrey (B-G) and Breusch-Godfrey-Pagan (B-G-P) LM tests, at 5% significance. The residuals are also determined to follow a normal distribution, based on the Jarque-Bera (J-B) test, and the model shows no signs of mis-specification, based on the Ramsey RESET test. Finally, the VAR (4) also appears to be dynamically stable, as all roots are contained within the unit circle.[2]

Table 2. VAR Diagnostics Tests

Dependent Variable	**Adj. R^2**	**B-G-P**	**B-G**	**J-B**	**RESET**
E	0.995	1.36	1.62	0.35	0.23
Y	0.999	0.63	5.54*	0.26	2.50
CO	0.986	0.47	1.55	3.36	4.18
L	0.999	0.60	3.01	1.55	0.18
K	0.992	0.69	1.51	1.30	1.83

*Denotes significance at 5% . The null hypotheses of the B-G and B-G-P tests are serial independence; the null hypothesis of the J-B test is normality; the null hypothesis of the RESET test is no mis-specification.

Based on the VAR (4), the results of the Johansen trace and max eigenvalue cointegration tests both indicate that there are three cointegrating vectors, which indicates that there is causation between the variables in this system.

[2] Results of this test are available upon request.

4.3 Direct Granger causality tests

Following the TY approach, a VAR (4) is estimated with constant and trend, and one lag of all variables are included as exogenous variables. Table 3 presents Granger causality results:

Table 3. Granger causality results

Null Hypothesis	Wald statistic	P-value	Causality
Energy does not Granger cause Income	16.48	0.00	E->Y
Energy does not Granger cause Emissions	4.15	0.38	
Income does not Granger cause energy	15.76	0.00	Y->E
Income does not Granger cause emissions	1.81	0.76	
Emissions do not Granger cause energy	5.50	0.23	
Emissions do not Granger cause Income	2.17	0.70	

The results indicate that there is bi-directional causality between energy and income, but no other channel of causality. The former result is not a surprise, as it is a result found by Ghali and El-Sakka (2004) and confirmed by Soytas and Sari (2006). The fact that income does not Granger-cause emissions is consistent with Soytas et al. (2007) in the US. Day and Grafton (2003) found uni-directional causality between income and CO_2 emissions in Canada. This difference could be attributed to the fact that they used a different sample period and per capita income.

From a policy perspective, these results imply that reducing emissions by reducing energy use will have a negative impact on economic growth. Therefore, policy in Canada should focus on developing and adopting new technologies, to reduce GHG without impacting overall energy use. Further, since income does not Granger-cause emissions, there does not seem to be a direct trade-off between income and emissions. This is a result found by Soytas et al. (2007) in the US, which implies that Canada does not need to accept a reduction in income in order to reduce emissions. Further, absent a causal relationship, countries cannot grow out of their emission problems, as assumed in the EKC literature. This reiterates the need to invest in alternative technologies to reduce greenhouse gas emissions without impacting energy use.

4.4 Indirect Granger causality testing

Following the method of Dufour et al. (2006), we estimate the unrestricted VAR(4) specified above at each of h different horizons into the future. The optimal horizon, as determined by Dufour et al. (2006) is the number of auxiliary variables multiplied by lag length, plus one, which is nine in our case. It is assumed that non-causality up to horizon 9 is sufficiency for non-causality at all horizons. At each horizon, we estimate Equation (6) using SUR with HAC estimates, and test for Granger causality using the TY approach. Table 4 presents the directions of causality found, at the 5% significance level.

Table 4. Indirect Causality Results

Causality	Horizon
E->Y	1, 2
Y->E	1, 2, 4
Y->CO	2, 3, 4, 5
CO->Y	6, 7, 8
E->CO	3, 7
CO->E	5, 6, 7

The results in Table 4 indicate that there is bidirectional causality between energy and income, income and emissions, and energy and emissions at various horizons. The results also show the period of time that it takes for these effects to occur. Note that the tests were also conducted using a VAR model with two extra lags as independent variables, to allow for the possibility that the data are I(2). Results were almost identical in that case, and the overall result holds that there is no direct causality between any variables except energy and income, but bi-directional causality between all variables at multiple horizons. Thus, we proceed to discuss the results in Table 4, under our initial assumption that data are I(1).

Salamaliki and Venetis (2013) tested for multi-horizon causality with a model including energy, income and capital. This allowed them to isolate the indirect causal link between income and energy, through capital. In our study, we have multiple auxiliary variables, and understanding exactly why one variable will indirectly impact another is more complicated. However, based on the indirect causality results[3], we can conceive of indirect channels of causality that are plausible and intuitive. As discussed above, we focus on the relationship between income and emissions, since the bi-directional causality result found here is contrary to other results in the literature in Canada, as well as the one-period-ahead results above. The indirect causal effect of income on emissions occurs after two years, likely via the direct (one-period-ahead) causal impact of income on labour. Increased economic activity and therefore increased labour force will increase emissions via a more populated economy. The impact of emissions on income, which is not found in other studies, takes longer to occur. Based on the results of the indirect Granger causality tests, it is conceivable that emissions impact income via the causal effect on capital stock four periods ahead (more capital is required to combat emissions). Capital then has a one-period-ahead impact on income.

The fact that there is bi-directional causality between income and emissions and emissions and energy that were not found using direct causality tests has important implications for this line of research. Clearly, the results of indirect (multi-horizon) causality testing may determine channels of causality not found in direct (one-period-ahead) Granger causality tests. A bi-causal relationship between income and emissions is contrary to the results in Day and Grafton (2003) and Hamit-Haggar (2012). Thus, traditional EKC models that estimate the effects of income on emissions are not capturing this important feedback effect. The results of these tests also reinforce the notion that it is important to include auxiliary variables in a multivariate model, as interactions in the system can cause indirect (multi-horizon), as well as direct (one-period-ahead) causal effects. It also illustrates how many causal relationships may occur at different periods, which has implications for the timing of policy aimed at mitigation. Finally, these results call into question previous results in the literature, and the associated policy conclusions, which rely on direct causality tests in a multivariate model. The policy implications from this study will be discussed in detail in the conclusion.

5. Conclusions and Policy Implications

This paper tested for Granger causality between income, emissions and energy use in Canada. This work has tied together two relatively large bodies of literature into one framework, as has recently been done in studies of other countries (Soytas et al., 2007; Ang, 2007). We analyze causality between these related variables in the same multivariate framework, relying on recent econometric developments. Further, this work has used newly developed methods of indirect Granger causality (Dufour et al., 1998, 2006) to test for multi-horizon causality in the absence of direct causality.

The results suggest that there is direct bi-directional causality between energy and income in Canada; however there were no other channels of direct causality between the variables. However, by testing for indirect causality up to nine periods ahead, it was apparent that there are channels of causality running bi-directionally through all the variables at multiple horizons. This result suggests that causality may take some time to occur through other variables. It also raises questions about studies in the literature that do not allow for feedback effects from emissions to income, or multivariate studies that do not find causality between energy and income or income and emissions. Finally, it implies that policy formulated from studies based solely on direct causality tests may be misinformed.

It is clear that the policy implications outlined above, based on direct causality tests, will not hold in the face of the multi-horizon results. Particularly, as in Soytas et al. (2007) for the US, it was argued above that since income and emissions are not found to have a causal relationship, Canada does not have to accept an income reduction in order to reduce emissions. Rather, a reduction in energy content could be used to reduce emissions, as well as reliance on fossil fuels. However, the policy implications for Canada based on the multi-horizon causality tests imply that (a) reduced

[3] Since there are too many p-values to report in one table, we just focus on the causal links found. Full results of indirect causality between all variables are available upon request.

energy use will adversely impact income (b) there is a trade-off between income growth and greenhouse gas emissions, and (c) bi-directional causality between income and emissions implies that Canada cannot simply grow out of its emissions problems. The last result follows from the fact that even if increased growth will decrease emissions in the long run, as assumed in the EKC literature, there will be an additional feedback effect from emissions to income. There is no simple way to reduce energy (fossil fuel) use and emissions in Canada without impacting income growth. The three variables are interrelated and any policy to impact energy use and emissions will play out in complicated ways. Government should reduce energy content by adopting new technologies to produce clean energy. This will reduce greenhouse gas emissions without reducing energy use and income. However, the reduction in emissions will have a negative impact on income, via the long run feedback effect. The upshot is that we can conclude that any 'simple' policy recommendations are likely too good to be true if all of these variables are interrelated. It seems clear that some impact on growth should be expected if ambitious climate change goals are pursued. The magnitude of this effect is left for future research.

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