



## ENERGY USE TENDENCIES IN A RESOURCE-ABUNDANT COUNTRY: THE CASE OF CANADA

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**Abstract.** Today's global energy agenda focuses especially on the fields of increasing energy demand, security of supply and climate change. This situation causes the energy efficiency phenomenon to be considered by policymakers seriously, and additionally to be developed strategies by determining targets in this field. In this sense, it is thought that developments in the field of energy efficiency will increase energy savings and reduce emissions caused by high consumption. On the other hand, the expected improvements in energy saving based on consumer behavior are less than anticipated. In measuring the mentioned dimension, one of the important parameters is defined as the rebound effect. This effect is considered as a dilemma that is frequently emphasized, especially in developed countries since there is a prevailing opinion that the developments in energy efficiency may not cause the expected results in savings. Therefore, it is extremely important to accurately measure the dimensions of the said effect in terms of both guiding policymakers in their strategies on energy efficiency and preventing waste of resources. This study tests the validity of the rebound effect for Canada using annual data from 1972 to 2019. In the study, the Fourier Engle-Granger Cointegration Test, which is one of the current econometric methods, was used, and then FMOLS, CCR and DOLS methods were utilized for the estimation of the short- and long-term coefficients. Empirical findings suggest that increases in energy efficiency in Canada increase energy consumption. Thus, it can be said that the rebound effect is valid for Canada.

**Keywords:** Fourier Engle-Granger Cointegration; Total Factor Productivity; Rebound Effect; Canada

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## 1. Introduction

Energy is one of the necessary elements in today's world. Since the early ages, energy has been a factor that has been used in many different areas such as transportation, commerce, housing, and industry. In this context, energy resources are considered as serious inputs for modern economies.

The energy resources push countries to some competition since they are such important. The desire to reach more energy at more affordable costs is the center of the countries' agenda. Moreover, countries are faced with the challenge of the tendency to consume energy resources without harming the environment more than ever. All

these issues force countries to take measures in terms of alternative energy resources. Among these measures, the concept of energy efficiency comes to the fore.

Efficient energy usage means that the same (or more) output level is obtained by utilizing the less (or same) energy input. This situation depends on the technological developments. In this sense, developments in total factor productivity with technological progress will cause less resource utilization. The reason behind this issue is that the increasing technological developments within the framework of efficiency lead to the transition to production and consumption processes that are less harmful to the environment, especially after the global COVID-19 pandemic. By this means, the improvement of environmental quality is raised.

Energy efficiency, which was not given much importance in the past, is now classified as a priority fuel in the context of the sustainability concept (International Energy Agency, 2021). Especially after the oil crisis in the 1970s, the developed and developing countries were deeply affected economically. In the recent period, on the other hand, the environmental dimension of energy consumption has come to the fore. In this context, the phenomenon of climate change has become an important issue that the whole world focuses on. That being said, the popularization of efficient resource consumption aims to reduce environmental pollution and climate change (Şahin and Önder, 2021). Therefore, these processes have motivated the decision-makers to develop alternative policies in the fields of conventional fuel dependence, security of supply, increasing energy demand, environmental problems, and sustainability. One of these alternatives is energy efficiency. However, there are different views in the literature on whether the energy efficiency affects the energy consumption or not.

One of the prominent concepts in this field is the rebound effect. The rebound effect term is broadly used to explain the process of falling costs in energy services as a result of technological progress. In other words, as a result of the developments in energy efficiency, some or all of the expected decline in energy consumption is balanced by energy demand increases.

According to the Rebound Effect approach, technological improvements will result in output growth by reducing costs along with using fewer resources. Therefore, it is argued that initially while the demand for energy resources decreases with the increase in energy efficiency, later decreases in demand and costs may cause a rebound process (Gottron, 2001:1). When evaluated from this aspect, the actions of the political authority to increase the energy efficiency may not cause the expected results in energy saving through the Rebound Effect. This situation is illustrated in Figure 1.

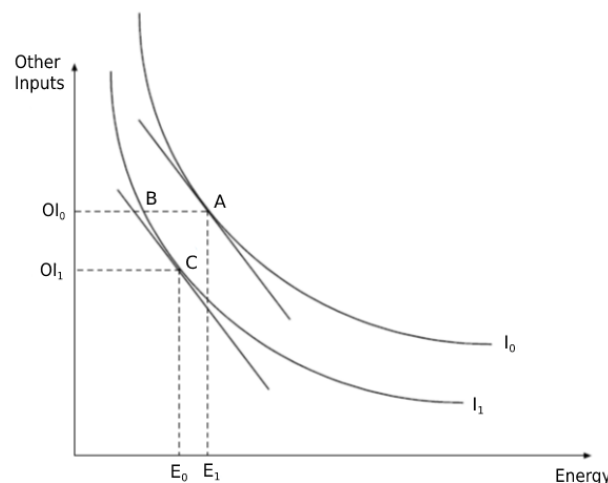


**Fig. 1.** Rebound Effect  
Source: Birol and Keppler, 2000

In the figure above, the isoquant curves  $I_0$  and  $I_1$  demonstrate before and after the increases in energy efficiency, respectively. An increase in energy efficiency simply means that less energy is physically required for a given amount of output and then the isoquant curve is shifted to the left. Before the increase in efficiency, the factors of production are  $E_0$  and  $IO_0$ , where  $E$  is energy and  $IO$  is other inputs. The combination of these factors of production (at point A) is determined by the firm regarding the minimum cost principle. At this point, the slope of the isoquant curve (marginal rate of substitution between factors of production) is equal to the relative price between energy and other inputs.

While the energy efficiency improves, the amount of other inputs remains constant ( $IO_0$ ) and the isoquant curve is shifted to the left, the combination of factors of production will be point B in the figure. In this case, all energy efficiency increases will be reflected in the reduced energy intensity. However, this point will not be the new equilibrium, since physically the relative price of energy does not change (or the relative price is lowered in terms of efficiency). The final production combination will be  $E_1$  and  $IO_1$  which is the new minimum cost combination. At point C, a substitution is made between energy and other inputs. Thus, the eventual reduction in energy use and consequent reduction in energy intensity is not as large as the original energy efficiency increase. At this stage, the difference between point B and point C in terms of energy use is called as the rebound effect.

The validity of the rebound effect is widely accepted in the energy economy literature and generally accepted. The most obvious disagreement on this issue is about the size of this effect. When this effect is less than 100%, developments in the field of energy efficiency will make a positive contribution to reducing total consumption and carbon emissions. On the other hand, if the same effect is greater than 100%, the energy demand after the efficiency improvements will increase more than before, and thus efficiency improvements will increase the use of energy resources. Therefore, measuring the rebound effect properly is very important in terms of both guiding policymakers and preventing waste of resources.

Measuring the rebound effect starts with a simple question: Does a 10% increase in energy efficiency reduce energy consumption by 10%? While we know that technological progress will improve energy efficiency, the answer is likely to be no. Although the developments in the field of energy efficiency have a reducing effect on consumption, this effect is not at the same level as the consumption level.

For the purpose of answering the question above empirically, this study investigates the relationship between total factor productivity and energy consumption for Canada with the current econometric method using annual data for the period 1972-2019. In this context, the effects of economic growth, trade openness, and total factor productivity on energy use are investigated for the Canadian economy. Findings show that increasing total factor productivity in Canada increases energy consumption in the related period. Therefore, it is concluded that the rebound effect is valid for Canada.

In this study, Canada was chosen as a case study, where the rebound effect phenomenon has not been investigated broadly in the literature. In addition, the use of dynamics that cause an increase in energy consumption such as total factor productivity, trade openness, and economic growth may accepted as contributions to the literature. Finally, it is aimed that this study can contribute to the research area by revealing the relationship between the variables with a cointegration test that has recently been introduced to the literature. In addition, the findings obtained from this article contain concrete information for the Canadian economy.

In the next section, the related literature review is given. Afterwards, empirical models, methods, and results are presented. Finally, in the conclusion part, several policy recommendations will be made within the scope of the key findings.

## 2. Literature Review

There are many theoretical and empirical studies in the literature analyzing the rebound effect. Empirical research uses elasticity calculations of variables such as price and efficiency when measuring the rebound effect (Sorrell and Dimitropoulos, 2008). The selection of these variables is generally determined in the context of the theoretical framework.

The first studies in the related field date back to the 1980s (Brookes, 1979; Khazzoom, 1980). In these studies, energy consumption sectors such as personal car transportation and residential heating were examined (Sorrell et al., 2009: 23). While these studies, which deal with different sectors, differ in terms of the method and data set used, research areas are generally evaluated in the context of the accessibility of the relevant data.

When the recent literature on the rebound effect is examined, besides country-based research, studies on household electricity consumption, the transportation sector, and the industry sector stand out in general. In addition, in the recent period, it is noteworthy that the studies conducted especially in China are high in number (Wang et al., 2014; Lin and Liu, 2015; Zhang and Peng, 2017; Zhang and Lin, 2018; Liu et al., 2019; Lin and Zhu, 2021; Meng and Li, 2022). The reason is that China has the highest energy demand increase globally. Therefore, it is important to measure the rebound effect with different methods and accurately designed models for this country.

When the literature is reviewed as a whole, the primary debate focuses on whether the developments in the field of energy efficiency reduce energy consumption. The basic assumption in this topic is that efficient energy usage will reduce the energy demand. However, since the improvements made in the field of efficiency do not always reduce energy consumption as expected, there are also findings in the literature that do not fully support the above-mentioned view.

Greene (1992) calculated the rebound effect of light vehicle use in the United States (USA) for the period of 1966-1989 by applying the Least Squares method. He concluded that the said effect is in the range between 5%-15% and quite small for the short term. According to the findings, technological advances in the transportation sector cannot reduce the energy consumption in light vehicle usage as much as desired. As a result, it was concluded that the fuel taxes should be increased at a high rate to reduce the use of vehicles.

Johansson and Schipper (1997) examined the rebound effect in the transport sector for 12 OECD countries between 1973 and 1992. According to the findings obtained in the study, the rebound effect in the relevant countries was calculated as -11% for the short term and -17% for the long term.

Haas and Biermayr (2000) calculated the rebound effect for residential heating in Austria using the cross-section method. The empirical results of this study suggest that the rebound effect varied between 20% and 30% for the examining period between 1970-1995.

In another study dealing with the USA, Bentzen (2004) examined the rebound effect in the manufacturing sector for the period 1949-1999. The results obtained by using the Dynamic Least Squares method indicate that the rebound effect in this sector was determined as 24%.

Jin (2007) investigated the rebound effect in household electricity consumption by using the price decomposition analysis method for South Korea between 1975 and 2005. In this study, the short- and long-term rebound effects were determined as 30% and 38%, respectively. In light of these results, it is emphasized that the rebound effect is an important factor when determining energy efficiency policies for South Korea.

Matos and Silva (2011) examined road transport in Portugal using data from 1987 to 2006. Using the two-stage least squares method, the authors calculated the rebound effect as 24.1%. In addition, in parallel with the results obtained in the study, it is emphasized that the rebound effect should be considered when determining any energy strategy.

Wang et al. (2014) evaluated the rebound effect on electricity consumption of urban households in China, using daily data to examine the period between 1997 and 2011. In the study, while household electricity consumption was chosen as the dependent variable, the independent variables were determined as per capita disposable income, average air temperature, electricity price, and urban population. Panel cointegration test and error correction model was utilized in this study, and the rebound effects were calculated as 72% for the short-term and 74% for the long-term. Therefore, a weak rebound effect is identified for urban households in China.

Orea et al. (2015) analyzed the 48 US states for the period between 1995 and 2011. They used a frontier model with a panel dataset to investigate the household rebound effect. The findings indicate that the rebound effect for the selected states varies between 56% and 80%. As a policy recommendation of the study, it is determined that policymakers should consider the fact that expected energy savings from efficiency improvements in the USA are not very consistent.

Using the ARDL model for the period between 1964 and 2009, Topallı and Bulus (2016) calculated the rebound effect as 18% for Türkiye's household electricity demand. According to the results, it is emphasized that the rebound effect based on the progress in the field of energy efficiency is low in Türkiye and the country should focus more on this area.

Bataille and Melton (2017) analyzed the rebound effect for the Canadian economy, which is also the subject of this study, with the General Equilibrium Model. A general evaluation has been made in this study by considering many sectors of the country such as services, mining, iron, and steel, transportation, and energy for the period between 2002 and 2012. The findings show that the rebound effect for the Canadian economy is on average 69%. Furthermore, there is a tight correlation between energy efficiency and economic activities in the country.

As mentioned before, there are a lot of studies related to China in the literature. One of them, Liu et al. (2019), examined the rebound effect in China's industrial sector using the Logarithmic Average Divisia Index. The rebound effect in the industrial sector for the 1994-2015 period was found to be 37%. In this respect, it is deduced that a significant part of the rebound effect in the Chinese industrial sector is due to the cost reduction as a result of efficiency investments.

Adha et al. (2021) examined the rebound effect on the Indonesian economy using data from 2002 to 2018. In this study, they emphasized the importance of determining the size of the rebound effect when

establishing the policies of governments regarding energy efficiency and carbon emissions. In this context, the authors calculated the rebound effect as 87.2% and -45.5% for the short- and long-term, respectively. It has been concluded that the developments in energy efficiency increased energy consumption in Indonesia.

Steren et al. (2022), in their study, investigated whether household car usage causes a rebound effect in Israel. The researchers used cross-sectional data examining the 10 years between 2007 and 2016 in their study. By using the 2-Stage Least Squares and ‘Rolling Window’ methods, the rebound effect was determined as 62%. This finding shows that policies that encourage consumers to buy energy-efficient vehicles may not reduce energy consumption in the long run.

In a recent study, the rebound effect was found between 10% and 50% for Spain by applying structural decomposition analysis. (Cansino et al., 2022). According to the results, it was concluded that the rebound effect increased during the recession periods in the Spanish economy.

Another recent study investigated the rebound effect on the Iranian economy by using the structural vector autoregressive model and the quarterly data set covering the 1988:3 and 2018:1 periods (Jafari et al., 2022). As a result of the analysis, it is determined that the rebound effect for Iran is calculated as 84%. In this sense, the reversal of the energy intensity increases in the country is determined as invalid with the adopted energy efficiency policies.

**Table 1.** Literature Summary

| Researcher(s)                 | Countries         | Time Period    | Focus of the Study    | Method(s)                                           | Results (Rebound Effect)               |
|-------------------------------|-------------------|----------------|-----------------------|-----------------------------------------------------|----------------------------------------|
| Greene (1992)                 | USA               | 1966-1989      | Transportation Sector | Least Squares                                       | %5-%15                                 |
| Johansson and Schipper (1997) | 12 OECD Countries | 1973-1992      | Transportation Sector | Least Squares                                       | Short Term: -%11<br>Long Term: -%17    |
| Haas and Biermayr (2000)      | Austria           | 1970-1995      | Residential Sector    | Cross Section Method                                | %20-%30                                |
| Bentzen (2004)                | USA               | 1949-1999      | Transportation Sector | DOLS                                                | %24                                    |
| Jin (2007)                    | South Korea       | 1975-2005      | Household             | Price Segregation Method                            | %30-%38                                |
| Matos and Silva (2011)        | Portugal          | 1987-2006      | Highway Transports    | 2-Stage Least Squares                               | %24,1                                  |
| Wang et al. (2014)            | China             | 1997-2011      | Household             | Panel Cointegration Test and Error Correction Model | Short Term: %72<br>Long Term: %74      |
| Orea et al. (2015)            | USA               | 1995-2011      | Household             | Boundary Model                                      | %56-%80                                |
| Topallı and Buluş (2016)      | Türkiye           | 1964-2009      | Household             | ARDL                                                | %18                                    |
| Bataille and Melton (2017)    | Canada            | 2002-2012      | General Economy       | General Equilibrium Model                           | %69                                    |
| Liu et al. (2019)             | China             | 1994-2015      | Industry Sector       | Logarithmic Mean Divisia Index                      | %37                                    |
| Adha et al. (2021)            | Indonesia         | 2002-2018      | Household             | Probabilistic Boundary Analysis                     | Short Term: %87,2<br>Long Term: -%45,5 |
| Steren et al. (2022)          | Israel            | 2007-2016      | Household             | 2-Stage Least Squares and Rolling Window            | %62                                    |
| Cansino et al. (2022)         | Spain             | 2000-2014      | General Economy       | Structural Decomposition Analysis                   | %10-%50                                |
| Jafari et al. (2022)          | Iran              | 1988:3 -2018:1 | General Economy       | Structural VAR Model                                | %84                                    |

### 3. Data and Methodology

In this section, the relationship among energy consumption (ENC) total factor productivity (TFP), real GDP (GDP) and trade openness (TRD) will be analysed by using econometric methods. The functional form of this relationship is given in Equation (1).

$$ENC_t = f(TFP_t, GDP_t, TRD_t) \quad (1)$$

#### 3.1. Data

In this study, for testing the validity of the rebound effect in Canada, energy consumption (ENC) which is total energy use (ktoe) was taken as the dependent variable. The independent variables are total factor productivity (TFP), real GDP (GDP) and trade openness (TRD). The TFP variable is given as an index (input/output) which represents energy efficiency and/or technological development parameters. In addition, the study period was limited to 2019, since the most recent data for the TFP variable belongs to 2019. On the other hand, real GDP was taken as GDP per capita (US\$ 2010 base year) and TRD as the share of exports and imports in total GDP. Data were provided from different databases. Energy consumption, and total factor productivity were obtained from the International Energy Agency (IEA, 2021), and the Penn World Table (2021), respectively. The real GDP and trade openness were gained from the World Bank (World Bank, 2021). All variables were transferred into natural logarithms form.

#### 3.2. Econometric Methodology

In this part of the study, first of all, the stationarity of the series will be investigated. For this purpose, primarily traditional ADF and current Fourier ADF unit root tests will be used. Then, the cointegration relationship between the variables will be examined. In this context, the Fourier Engle-Granger Cointegration test, which was recently introduced to the literature by Yılancı (2019), will be used. Finally, Fully Modified Least Squares (FMOLS), Dynamic Least Squares (DOLS) and Canonical Co-integrated Regression (CCR) methods will be utilized for short- and long-term coefficient estimation for the variables.

In the traditional ADF unit root test, the structural changes that can be found in the variables are not considered. Therefore, a variable with structural change can be obtained as stationary. This may adversely affect the reliability of the method to be used and the results to be obtained. Therefore, the tests that considered structural changes can increase the reliability of the test results.

Structural breaks are considered in the stationarity tests introduced to the literature by Enders and Lee (2012). For this purpose, low-frequency trigonometric functions are used in testing procedures. This test can also eliminate the problems related to the amount and time of the structural changes in the series. Moreover, in this test developed by Enders and Lee (2012), the structural breaks can be captured by including sine and cosine functions in the Fourier functions. However, one of the important issues in this process is to determine the frequency value. The standard ADF equation is given in the below:

$$\Delta y_t = \rho y_{t-1} + \beta_1 + \beta_2 trend_t \quad (2)$$

Enders and Lee (2012) obtained the following model by including trigonometric sine and cosine functions in Equation (2),

$$\Delta y_t = \rho y_{t-1} + \beta_1 + \beta_2 trend + \beta_3 \sin\left(\frac{2\pi kt}{T}\right) + \beta_4 \cos\left(\frac{2\pi kt}{T}\right) + u_t \quad (3)$$

where  $t$  is the trend,  $T$  is the time and  $k$  is the frequency to be determined. In addition, while determining the frequency value in here, the frequency value with the Minimum estimation of the Residual Sum of Squares (MinSSR) will be used. Therefore, by determining the MinSSR estimation, the appropriate frequency value can be obtained.

Since all series are stationary after taking the first difference, the cointegration relationship is investigated with the idea that there may be a long-term relationship between the series. In recent years, the Fourier Engle-Granger Cointegration test has been introduced to the literature by Yılanıcı (2019). In this test developed by Yılanıcı (2019), the traditional Engle-Granger equation is transformed into Equation (4) by adding sine and cosine trigonometric functions.

$$y_t = \alpha_0 + \gamma_1 \sin\left(\frac{2\pi kt}{T}\right) + \gamma_2 \cos\left(\frac{2\pi kt}{T}\right) + \beta' y_{2t} + u_t \quad (4)$$

Where,  $k$  represents the frequency value and the models are estimated by taking  $k=1, \dots, 5$  values. The important thing for this test is to determine the appropriate  $k$  frequency value for MinSSR. The Fourier Engle-Granger Cointegration test is performed in two stages, as in the traditional Engle-Granger Cointegration test. First of all, sine and cosine trigonometric functions are added to the model as in Equation (4) and estimated with OLS. Then, residuals are obtained from this estimation. DF or ADF stationarity tests are applied for these residuals. The thing to note here is that the critical values of the traditional ADF test cannot be used since the Fourier functions are included in the model. At this point, the statistics obtained as a result of DF and ADF stationarity tests are compared with the critical values in Yılanıcı's (2019) article. As a result of this comparison, the cointegration relationship can be decided between the variables.

After finding the cointegration relationship between the variables, the coefficient estimates will be made for the magnitude and direction of the effect of the explanatory variables on the dependent variable. While estimating the coefficient, the Fully Modified Ordinary Least Squares (FMOLS) method developed by Phillips and Hansen (1990), will be used. One of the main advantages of this method is its ability to allow structural changes to be included in the model. In the process of estimating the coefficient with FMOLS, the relationship between the explanatory variables with the residuals and the deviations that may occur due to the endogeneity problem can be eliminated (Nazlıoğlu, 2010: 99). To increase the reliability of the coefficients obtained from FMOLS estimation, Canonical Co-integrated Regression (CCR) developed by Park (1992) and Dynamic Ordinary Least Squares (DOLS) estimator developed by Stock and Watson (1993) will be used as short and long coefficient estimators. For the CCR estimator, the endogeneity problem arising from the correlation that may occur in the long run can be eliminated asymptotically (Mehmood et al., 2014: 9).

In the DOLS estimator, on the other hand, dynamic elements are added to the process and problems such as endogeneity between the independent variable(s) and error term and self-correlation problems in error terms that may arise in static equations can be eliminated. In addition, the DOLS estimator is used because it gives effective results for low observations and heterogeneous series (Mark and Sul, 2003: 654).

#### 4. Empirical Results

To examine the cointegration process in the models, first of all, it is necessary to analyze the stationarity of the variables with unit root tests. For this purpose, standard ADF and Fourier ADF stationarity tests were applied to the variables. The test results are given in Table 2.

**Table 2.** Standard ADF and Fourier ADF Unit Root Test Results

| Level                | Frequency | MINSSR | Lag | FADF   | ADF       | F-Test  |
|----------------------|-----------|--------|-----|--------|-----------|---------|
| EC                   | 1         | 0.004  | 7   | -3.198 | -2.473    | 8.284** |
| TFV                  | 3         | 0.001  | 5   | -1.149 | -1.397    | 2.754   |
| GDP                  | 1         | 0.004  | 2   | -2.046 | -1.746    | 1.650   |
| TRD                  | 2         | 0.018  | 5   | -3.059 | -1.371    | 5.309   |
| 1 <sup>st</sup> Dif. | Frequency | MINSSR | Lag | FADF   | ADF       | F-Test  |
| $\Delta$ EC          | 5         | 0.004  | 1   | -6.609 | -5.706*** | 3.168   |
| $\Delta$ TFV         | 2         | 0.001  | 4   | -3.336 | -5.591*** | 2.574   |
| $\Delta$ GDP         | 5         | 0.004  | 1   | -5.822 | -4.915*** | 2.133   |
| $\Delta$ TRD         | 2         | 0.019  | 1   | -4.890 | -5.706*** | 2.329   |

**Note:** F test critical values 1%=10.35%, 5%=7.58, 10%=6.35%, Fourier ADF k=1 critical values 1%=-4.42%, 5%=-3.81, 10%=-3.49%, ADF critical values % The values of 1=-3.753, 5%=-2.998, 10%=-2.639, \*\*\*, \*\* and \* indicate that the series are stationary at 1%, 5% and 10% significance levels, respectively.

When Table 2 is examined, as the F test for energy consumption (EC) is statistically significant at the 5% significance level, there is a unit root at the level according to the Fourier ADF test results. The F test was not estimated as significant at the level for the other variables. Therefore, these variables have unit root according to the standard ADF test. Then the first difference of the variables was taken. The F test for all variables was statistically insignificant. As a result, all variables are stationary at first difference according to Standard ADF test results. Furthermore, the integrated degree of all variables is obtained as I(1).

In the second stage of the analysis, the cointegration relationship between total factor productivity, economic growth, and trade openness with energy consumption for Canada was investigated with the Fourier Engle-Granger cointegration test. The results are shown in Table 3.

**Table 3.** Fourier Engle-Granger Cointegration Test Results

| Dependent Variable | Independent Variables | Frequency | MINSSR | Fourier Engle-Granger Cointegration Test Statistic |
|--------------------|-----------------------|-----------|--------|----------------------------------------------------|
| EC                 | TFV, GDP, TRD         | 1         | 0.004  | -4.351*                                            |

**Note:** Critical values for the Fourier Engle-Granger cointegration test are 1%=-5.271, 5%=-4.605, 10%=-4.252, and \* indicates significance at the 10% significance level.

It can be seen from Table 3 that the MINSSR was obtained as 0.004 for the Fourier Engle-Granger cointegration test. The appropriate frequency value for MINSSR was found to be 1. In addition, since the test statistic is greater than the critical values at the 10% significance level, there is a cointegration relationship between the variables in the relevant period for Canada.

Since a cointegration relationship was found in the model, the FMOLS, DOLS, and CCR estimators were used for cointegration coefficient estimation as a third stage of the study. The results can be seen in Table 4.

**Table 4.** Long-Run Coefficient Estimation Results

| Methods | TFV                 | GDP                 | TRD                | C                   |
|---------|---------------------|---------------------|--------------------|---------------------|
| FMOLS   | 0.810***<br>(0.241) | 0.083**<br>(0.032)  | 0.100**<br>(0.045) | 3.345***<br>(0.143) |
| DOLS    | 0.690**<br>(0.304)  | 0.105***<br>(0.037) | 0.083<br>(0.056)   | 3.272***<br>(0.162) |
| CCR     | 0.788***<br>(0.246) | 0.085***<br>(0.029) | 0.099**<br>(0.044) | 3.333***<br>(0.125) |

**Note:** \*\* and \*\*\* indicates (5%) and (1%) significance levels, respectively.

It can be seen from Table 4 that the size and sign of the variables had similar results for almost all estimators. According to these results, all variables have positive effects on energy consumption. Moreover, total factor productivity (TFV) has the most powerful impact on energy consumption among all estimators. On the other hand, economic growth (GDP) (for FMOLS and CCR) and trade openness (TRD) (for DOLS) have the weakest impacts on energy consumption. When analysed as a coefficient, according to FMOLS/DOLS (CCR) results, a 1% increase in total factor productivity (TFV) increases energy consumption (EC) by approximately 0.81%/0.69% (0.79%). On the other hand, for FMOLS/DOLS (CCR), a 1% increase in economic growth (GDP) and trade openness (TRD) increased energy consumption by 0.08%/0.11% (0.09%) and 0.10%/0.08% (0.10%), correspondingly. Therefore, the increase in total factor productivity (TFV) has an increasing effect on energy consumption EC, more than economic growth (GDP) and economic integration (TRD) in the long run.

In addition to what is stated above, the FMOLS, DOLS, and CCR error correction models were used for estimating the short-term coefficients. The related results are given in Table 5.

**Table 5.** Short-Run Coefficient Estimation Results

| Methods | ECT <sub>t-1</sub>   | $\Delta$ TFV      | $\Delta$ GDP        | $\Delta$ TRD        | C                  |
|---------|----------------------|-------------------|---------------------|---------------------|--------------------|
| FMOLS   | -0.358***<br>(0.071) | 0.235*<br>(0.136) | 0.326***<br>(0.072) | 0.235***<br>(0.136) | -0.001*<br>(0.001) |
| DOLS    | -0.398***<br>(0.115) | 0.193<br>(0.223)  | 0.344***<br>(0.115) | 0.117**<br>(0.051)  | -0.001<br>(0.001)  |
| CCR     | -0.347***<br>(0.078) | 0.284<br>(0.185)  | 0.316***<br>(0.095) | 0.124***<br>(0.038) | -0.001*<br>(0.001) |

**Note:** \* and \*\*\* indicates (10%) and (1%) significance levels, respectively

In parallel with the theoretical expectation, the error correction coefficient (ECT<sub>t-1</sub>), which expresses the long-term relationship between the errors, was found to be negative and statistically significant. Therefore, this result confirms that there is a long-run relationship between energy consumption (EC) and explanatory variables. In the theoretical framework, the error correction term (ECT<sub>t-1</sub>) denotes the correction rate. According to the FMOLS (-0.358) and DOLS (-0.398) models, approximately 36% and 40% of a variant at period t-1 will be corrected within 1 year. Similarly, the CCR (-0.345) model indicates that approximately 35% of a variant at period t-1 will be corrected within 1 year. Furthermore, as in the long-term, all variables have an increasing effect on energy consumption in the short term. According to the short-term results, economic growth has the most powerful impact on energy consumption among all estimators. In other respects, the trade deficit has the weakest effect on the above-mentioned parameter.

As a result, the positive coefficient of total factor productivity for the short and long run implies that the rebound effect is valid for Canada. Moreover, energy consumption and total factor productivity have a synchronical

relationship in the relevant period. In addition, the positive sign for the economic growth parameter in the short and long term indicates that higher growth causes higher energy consumption for the Canadian economy. Consequently, the short- and long-term results of this study reveal that the change in the total factor productivity, economic growth and trade openness increases the total energy consumption and especially the use of fossil fuels in Canada.

## 5. Conclusion and Policy Recommendations

The effects of industrialization and globalization around the world have increased the global energy demand in recent years. Population growth, widespread use of electronic devices in daily life, and production ambitions of economies also cause more energy demand. Since the high demand in question is met generally with fossil fuels, environmental destruction increases, and this hurts environmental sustainability which is difficult or impossible to return. The intense environmental problems have increased environmental awareness and pushed the countries to use their production factors more efficiently. Furthermore, efficiency provides significant opportunities for sustainable growth and environmental sustainability by causing minimum input for the same output. While efficiency is important for tackling environmental degradation, it does come with some concerns, such as the rebound effect.

The primary aim of this study is to investigate the effect of economic growth and trade openness on energy consumption between 1972 and 2019. In this context, Canada offers an ideal sample of research in terms of being a member of the G-7 countries and increasing the energy consumption among these country groups. Contrary to the studies in the literature, this study uses the Fourier Engle-Granger methodology, in which Fourier functions are added to capture structural changes gradually and smoothly.

According to the Fourier Engle-Granger cointegration test results, the variables used in this study move together in the long run. Moreover, the FMOLS estimation results suggest that the positive coefficient of total factor productivity provides evidence to support the rebound effect in Canada. In addition, DOLS and CCR results also support this effect. On the other hand, the increasing total factor productivity causes more energy consumption in Canada. This issue causes an overgrowth situation for the country. In this context, the growth increment causes more demand for energy. According to all three estimators, the significant positive effect of the GDP coefficient supports this situation.

The long-term empirical results provide evidence that environmental pollution has increased in Canada due to the efficiency improvements, since the increasing energy consumption is usually met with fossil fuels. Also, positive economic growth and trade openness in Canada have an increasing effect on dirty growth. As a result, while environmentally oriented energy policies require more investment, they should serve to encourage meeting the increasing energy demand with clean energy resources.

Short-term coefficient estimations support the critical role of clean energy and efficiency improvements in reducing environmental degradation as a result of increased economic growth, and trade openness. In addition, short-term findings show that externalities in energy consumption will be adjusted within one year.

The results obtained in the study are important in terms of being a guide for policymakers. First of all, one of the most important reasons behind the rebound effect is the increase in the unconscious consumption of resources with the ambition of production and competition. Considering that fossil fuels have the highest share among the total energy resources of the Canadian economy, increasing energy consumption creates a negative situation for sustainable growth and environmental improvement. Therefore, it is important to increase clean energy consumption awareness in Canada as well as to create environmental awareness. Besides, it will be important to increase the share of renewable energy and nuclear energy use, which can be an alternative to fossil fuels. In this

way, the increasing energy demand in response to the increasing total factor productivity will be met with environmentally friendly energy resources. Therefore, the negative impacts rebound effect for the Canadian economy will be met by clean energy technologies. Increasing green energy use is extremely important in terms of sustainable energy supply.

On the other hand, as it is expected, higher economic growth results in higher energy consumption for Canada. Despite the increasing growth, the rise in the use of efficiency technologies in the field of energy will offer significant opportunities. Besides, it should be ensured that environmental-oriented policies are adopted and effectively implemented in Canada. On the other hand, considering that the Canadian economy has a high share of fossil fuels in energy production processes, the country will not be able to abandon fossil fuels soon. Therefore, technological advances in the field of fossil fuels will also be important for Canada.

In addition, trade openness enables developing economies to import advanced technologies from developed economies. The adoption of advanced technology increases energy efficiency. Therefore, the foreign trade openness ratio is shaped by the advantage of either the gains arising from technological efficiency or the negative effects of energy waste caused by excessive production. In this context, increasing foreign trade for Canada also causes an increase in energy efficiency. However, more production with gains in efficiency causes an increase in energy demand.

Moreover, it can be considered that Canada's GDP is more integrated with fossil fuels due to its high share of fossil fuels. Therefore, increasing income should increase the use of energy-efficient technologies.. Therefore, the increase in these policies will open the way to use alternative and clean energy to ensure sustainable economic growth. Also, these results encourage policymakers in Canada to meet the increasing energy demand with clean energy in response to increasing factor productivity.

This study has some limitations as it focuses on the use of total factor productivity to test the rebound effect. In this respect, future research can focus on the efficient use of energy and technological developments in the field of energy instead of or together with total factor productivity. In addition, determining the type of technological developments in the energy sector can give important clues in terms of learning the source of the rebound effect.

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