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# Causal Relatıonshıp Between Energy Taxes and Green Innovatıon in G-7 Countrıes: New Evıdence Based on Fourıer Functıons

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This study explores the link between energy taxes and green innovation in G-7 countries from 1994 to 2019, using a novel Panel Fourier causality test which does not require determining the number, dates, and forms of breaks in advance. The study found that energy taxes cause green innovation in Canada, France, Italy, and the United Kingdom. The results suggest that energy taxes play a vital role in boosting environmental technologies in G-7 countries.

## I. Introductıon

Climate change is a serious issue, because it has significant and potential catastrophic environmental impacts. For instance, it leads to rising sea levels and extreme events such as droughts, floods, and hurricanes. It also seriously threatens biodiversity and ecosystems, as rising temperatures and changing weather patterns adversely affect ecosystems. Furthermore, climate change negatively impacts sustainable economic growth and environmental degradation.Carbon emissions cause climate change due to urbanization, industrialization, mass production, and the excessive use of non-renewable energy sources. Therefore, governments aim to reduce carbon emissions by implementing environmental policies. These policies include reducing the use of fossil fuels, supporting renewable energy, and applying environmental taxes.

Regarding environmental taxes, governments mostly implement energy taxes, which considerably combat the adverse effects of climate change. When governments tax industries that contribute to $CO_2$ emissions, they can incentivize industries to invest in research and development (*R&D*) expenditure for green innovation, which greatly counters climate change and ensures sustainable economic growth.

Carbon dioxide emissions that are generated by firms are a negative externality, because they cost society by harming the environment. Negative externality occurs when a person or firm engages in an activity that harms others without the others' consent. A person or firm causing externality does not bear its full cost; thus, they continue to engage in such activities. The government uses taxes to externalize these costs, known as externality-correcting taxes or Pigouvian taxes (Lucas, 2023). The negative externalities like global warming and carbon emissions have been tested based on Porter's (1991) hypothesis, which states that well-designed environmental policies can promote green innovation.

Oates et al. (1993) tested the Porter hypothesis by using the simple profit-maximizing firm model. They concluded that an increase in pollution tax rates compels firms to adopt efficient technology. Similarly, Jaffe and Palmer (1997) investigated the impact of R&D expenditure and patent applications on pollution abatement cost in the USA by employing the panel data method. They found a positive relationship between the pollution abatement cost and R&D expenditure and a statistically insignificant relationship between the cost and patent applications. Nakada (2004) stated that while environmental taxes can be a financial burden on companies, they can be offset by investments in R&D, resulting in technological innovation. Brunnermeier and Cohen (2003) found that environmental innovation measured by patent applications increases as the pollution abatement expenditure increases. Arimura et al.'s (2007) cross-sectional study investigated the impact of environmental regulation stringency on environmentally innovative R&D and found a positive link between environmental regulation stringency and investment in R&D.

Research on the impact of environmental taxes on green innovation has recently developed rapidly. Yang et al. (2020) found that carbon taxes can encourage innovation and support the transition to green innovation, particularly when combined with subsidies for advanced technologies. Recently, Wang & Yu (2021) discovered that the air pollution tax rate non-linearly affects green technology innovation in China. Castellacci & Lie's (2017) cluster and multinomial logit analysis revealed that R&D policies increase innovation in waste-reduction firms. Environmental

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taxes and regulations are associated with technological innovation in pollution-reduction firms. Song et al.'s (2020) study examined the impact of environmental regulation and tax incentives on the development of green products. They found that R&D tax incentives in China encourage green product innovation. Similarly, Huang et al. (2022) found that environmental taxes and regulations positively affect green innovation in China.

Wang et al. (2023) found a negative correlation between environmental protection tax and green innovation in China. Similarly, Tingbani et al. (2021) discovered that environmental taxes negatively affected small and medium enterprises' ability to green innovate in 24 The Organization for Economic Co-operation and Development (*OECD*) countries from 2000 to 2019.

This study explored the link between energy taxes and green innovation in G-7 countries from 1994 to 2019 and made two significant contributions to the existing literature. Firstly, it employed a novel causality test based on Fourier functions, thereby enabling the investigation of multiple structural breaks, cross-section dependence, and country heterogeneity. Additionally, the test also considered both sharp and smooth breaks simultaneously. Second, this study used the longest and most recent dataset.

This paper is structured as follows: Section I begins with an introduction; Section II introduces the dataset and explains the methodology via equations; Section III presents the empirical results; and Section IV suggests policy recommendations based on the results.

## II. Data and Methodology

### A. Data

Data was gathered from the OECD Database, spanning 1994 to 2019, because environmental-related patent applications data----used to measure green innovation----ended in 2019 and environmental taxes data begun in 1994 in the countries. The share of environmentally-related energy tax revenue in GDP was used as an indicator of energy taxes.

### B. Methodology

This study employed a causality test. Granger (1969) introduced the concept of causality analysis by utilizing Vector Autoregression (*VAR*) methods to investigate the relationship between variables. However, this test can only be conducted if the variables are stationary or cointegrated. Prior tests, such as the unit root test, are necessary to employ the Granger test. Thus, Toda-Yamamoto (1995) developed a new test that can be conducted if the variables are neither stationary nor cointegrated. Nevertheless, the Granger (1969) and Toda-Yamamoto (1995) tests usually reject the null hypothesis in cases of structural breaks. Recent literature has utilized the Fourier function to address this issue, as demonstrated in Equation (1).

$$d_{it} = a_{i0} + \sum_{k=1}^{n} a_{ik} \sin\left(\frac{2\pi kt}{T}\right) + \sum_{k=1}^{n} b_{ik} \cos\left(\frac{2\pi kt}{T}\right) \tag{1}$$

Where $d_{it}$ denotes the smooth function of time, $\pi$ is equal to 3.1416, and $T$ and $t$ are sample size and trend terms, respectively. Enders & Jones (2016) suggested a new test, using Fourier functions in *VAR* analysis, to accommodate structural breaks in causality analysis in time series, as shown in Equation (2) and (3).

$$Y_t = \alpha_{01} + \sum_{t=1}^{p} \alpha_{1i} Y_{t-i} + \sum_{t=1}^{p} \beta_{1i} X_{t-i} + \varnothing_1 \sin\left(\frac{2\pi kt}{T}\right) + \varnothing_2 \cos\left(\frac{2\pi kt}{T}\right) + e_{1t} \tag{2}$$

$$X_t = \alpha_{02} + \sum_{t=1}^{p} \alpha_{2i} Y_{t-i} + \sum_{t=1}^{p} \beta_{2i} X_{t-i} + \varnothing_3 \sin\left(\frac{2\pi kt}{T}\right) + \varnothing_4 \cos\left(\frac{2\pi kt}{T}\right) + e_{2t} \tag{3}$$

Furthermore, Nazlıoğlu et al. (2016) improved this test by adding Fourier functions to the Toda Yamamoto (1995) procedure as follows:

$$Y_t = \beta_0 + \beta_1 \sin\left(\frac{2\pi kt}{T}\right) + \beta_2 \cos\left(\frac{2\pi kt}{T}\right) + \sum_{t=1}^{1+dmax} \varnothing_i Y_{t-i} + \sum_{t=1}^{1+dmax} \varnothing_i X_{t-i} + u_t \tag{4}$$

$$X_t = \delta_0 + \delta_1 \sin\left(\frac{2\pi kt}{T}\right) + \delta_2 \cos\left(\frac{2\pi kt}{T}\right) + \sum_{t=1}^{1+dmax} \varnothing_i Y_{t-i} + \sum_{t=1}^{1+dmax} \varnothing_i X_{t-i} + v_t \tag{5}$$

A few panel data tests have been proposed recently, since Holtz-Eakin et al. (1988) proposed the panel causality test. Dumitrescu-Hurlin (2012) suggested the panel causality test based on Granger's (1969) method, as shown in Equation (6). However, as in Granger (1969), Dumitrescu-Hurlin (2012) did not consider structural breaks.

$$y_{i,t} = \alpha_i + \sum_{k=1}^{K} \gamma_i^{(k)} y_{i,t-k} + \sum_{k=1}^{K} \beta_i^{(k)} X_{i,t-k} + \varepsilon_{i,t} \tag{6}$$

For this reason, Yılancı & Kılcı (2021) suggested a panel version of Equation (6) that considers structural breaks by adding fourier functions $\left(\delta_i \sin\left(\frac{2\pi kt}{T}\right) + \theta_i \cos\left(\frac{2\pi kt}{T}\right)\right)$, as shown in Equation (7).

$$y_{i,t} = \alpha_i + \sum_{k=1}^{K} \gamma_i^{(k)} y_{i,t-k} + \sum_{k=1}^{K} \beta_i^{(k)} X_{i,t-k} + \delta_i \sin\left(\frac{2\pi kt}{T}\right) + \theta_i \cos\left(\frac{2\pi kt}{T}\right) + \varepsilon_{i,t} \tag{7}$$

This study used the model in Equation (7) to test the causality relationship between energy taxes and green innovation.

## III. Empırıcal results

### A. Preliminary test results

Firstly, this study investigated whether the variables employed were cross-sectionally dependent or not. Lagrange Multiplier (*LM*), Cross-section dependence Lagrange Multi-

**Table 1. Results of cross-section dependence and homogeneity tests**

| **Cross-section Dependence Tests** | **ENTAX>PATENT** |
|---|---|
| *LM* | 481.69 (0.000)*** |
| *CDLM* | 71.08 (0.000)*** |
| *CD* | 21.93(0.000)*** |
| **Slope Homogeneity Test** | ENTAX>PATENT |
| Delta_tilde | 5.658 (0.000)*** |
| Delta_tilde-adj | 6.015 (0.000)*** |

Note: *** indicates statistically significant at 1% level. Values in parentheses show the p-values. ENTAX and PATENT denote energy taxes and green innovation, respectively. LM (Lagrange Multiplier) CDLM (Cross-section Dependence Lagrange Multiplier) CD (Cross-section dependence).

**Table 2. MADF unit root test result**

| **Variables** | **Test statistic** | **Critical Value (5%)** |
|---|---|---|
| Patent | 70.076 | 49.619 |
| Entax | 35.779 | 31.844 |

Note: ENTAX and PATENT denote energy taxes and green innovation, respectively.

plier (*CDLM*), and Pesaran Cross-section dependence (*CD*) tests were used, and the results are presented in Table 1. From the table, the probability of these tests was less than the 1% level, implying the rejection of the null hypothesis of cross-section independence.

Based on the findings, a second-generation unit root test that accounts for cross-section dependence among variables was utilized. Among second-generation unit root tests, the Multivariate Augmented Dickey-Fuller (*MADF*) test is preferred, because it is more efficient when panel data consists of time dimension (*T*) > cross-section dimension (*N*). Table 2 presents the results of the MADF test. According to the table, the test statistics of two variables are greater than critical values, indicating that both variables are stationary.

To employ the Fourier Panel causality test, panel data should be heterogeneous. Therefore, this study tested the slope homogeneity (Hsiao, 2022) to determine whether the panel data was heterogeneous. The results are presented in Table 1; probability values were less than the 1% level, indicating that the panel data was heterogeneous.

## B. The main analysis results

After establishing heterogeneity, the study employed Dumitrescu-Hurlin (2012) and Fourier Panel causality tests. Table 3 comparatively presents the results of both tests. According to the Dumitrescu-Hurlin (2012) test, there was no causal relationship for any country or the entire panel. However, the Panel Fourier causality test revealed that energy taxes caused green innovation for the entire panel and four countries. Energy taxes cause green innovation in Canada, France, Italy and the UK, but not in Japan, Germany, and the USA. This finding shows the importance of structural breaks.

The main result obtained from this study shows that environmental taxes are important in stimulating green innovation and support the results obtained by Song et al. (2020), Huang et al. (2022), Yang et al. (2020), and Wang and Yu (2021). These results also confirm the Porter hypothesis.

# IV. Conclusıon

There has been a longstanding academic debate as to whether environmental taxes promote green innovation. This study aimed to investigate whether energy taxes promote green innovation based on a novel test named Fourier functions. A causal relationship between energy taxes and green innovation was found in four out of seven countries and across the entire panel. In other words, while energy taxes cause green innovation in Canada, France, Italy, and the UK, it does not cause green innovation in Germany, Japan, and the USA, because these countries do not have a carbon tax, and energy tax is mainly applied to the road sector.

The main result of this study showed that energy taxes promote green innovation in G-7 countries except Germany, Japan, and the USA. Therefore, governments should implement energy taxes to incentivize individuals and industries to reduce their carbon output and invest in R&D to invent new technologies that reduce carbon emissions.

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**Table 3. Panel causality test results**

| Countries | Dumitrescu-Hurlin (2012) | | Fourier Bootstrap Panel Causality | |
|---|---|---|---|---|
| | Optimal Lag | P-value | Optimal Lag | P-value |
| Canada | 6 | 0.815 | 1 | 0.000*** |
| France | 6 | 0.163 | 1 | 0.001*** |
| Germany | 6 | 0.503 | 1 | 0.870 |
| Italy | 6 | 0.558 | 1 | 0.004*** |
| Japan | 6 | 0.785 | 1 | 0.132 |
| UK | 6 | 0.308 | 2 | 0.031** |
| USA | 6 | 0.342 | 2 | 0.450 |
| Panel | | 0.0590 | | 0.000*** |

Note: **and *** indicate statistically significant at 5% and 1%, respectively.

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