Journal of Economics and Business Issues

Causal Relationship Between CO2 Emission, Renewable Energy, Trade Openness, Foreign Direct Investment and Output Volatility

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Abstract: This study explores the causal relationships between the Index of Industrial Production (IIP), output volatility (OV), renewable energy (RE), foreign direct investment (FDI), and trade openness (TO) across selected countries in East Asia and Pacific (EAP). Using Fourier panel causality test, we find RE causes OV in Australia and Malaysia, indicates short-term fluctuation. Conversely, FDI's impact on OV, especially in India, indicating the need for regulatory measures to manage FDI for economic steadiness. Policymakers should craft regulations on renewable energy investments to stabilize economic volatility. Additionally, the complex relationship between environmental policies and OV require integrated approach in policy design.

Keywords: Output Volatility; CO2 Emission; Renewable Energy; Trade Openness; FDI

Citation: Behera, C.; Zeren, F.; & Osanmaz, M. N. (**2025**) Causal Relationship Between CO2 Emission, Renewable Energy, Trade Openness, Foreign Direct Investment and Output Volatility. *Journal of Economics and Business Issues*, *5(1)*, 69-75.

Received: 30/12/2024
Accepted: 21/02/2025
Published: 28/02/2025

1. Introduction

Sustainable economy has been an area of interest for many, especially with climate change. This has become a necessity, especially in recent years. For instance, higher CO2 emissions increases output volatility (OV) by exposing industries to climate change hazards (Majeed et al., 2021; Genç et al., 2012). Climate change risks encompass extreme weather events, supply chain disruptions, and augmented input costs for industries. A company that heavily rely on natural resources, alterations in weather patterns due to climate change could reverberate through its production, thus affecting its OV. Conversely, renewable energy stands as a mitigating force against OV, achieved by diversifying energy sources and diminishing reliance on fossil fuels. Wind, solar, and hydropower, among other renewable sources, present reliable power reservoirs. Moreover, the stabilizing effect of renewable energy extends to energy prices, resulting in reduced output volatility for energy-intensive sectors like manufacturing and transportation.

This interplay between CO2 emissions, renewable energy, and OV presents a potential nexus that holds the attention of policymakers. On the other hand, OV can be impacted by macroeconomic variables such as foreign direct investment (FDI) and trade openness (TO). FDI reduces output volatility by providing a predictable source of investment and capital, in addition to stimulating economic growth. Furthermore, it facilitates access to new technologies, management practices, and global markets, thereby enhancing the competitiveness and resilience of local firms and industries. Similarly, TO decreases OV by diversifying markets and reducing dependence on a single market. Access to international markets ensures a stable source of demand, which in turn reduces OV. Additionally, TO provides access to inputs and resources that enhance the global competitiveness of domestic companies. Therefore, the presence of a relationship between OV and macroeconomic variables, in conjunction with environmental variables, is likely to be of interest to policymakers and academics.

More specifically, there have been numerous studies examining the relationship between climate change and economic growth, but their findings are mixed (Mendelsohn, 2009; Farhani et al., 2014; Zubair et al., 2020; Mohsin et al., 2022). According to Mendelsohn (2009), the actual impact of climate change on the global economy is projected to be minimal in the next 50 years. However, taking further corrective measures may pose a greater threat to long-term economic growth. Farhani et al. (2014) suggest that CO2 emissions originate from GDP, while Zubair et al. (2020) identify a long-term relationship between carbon emissions and GDP. Acaroğlu and Güllü (2022), reveal that increasing renewable energy consumption in Turkey can mitigate climate change by reducing temperatures, but non-renewable energy consumption can exacerbate climate change by increasing precipitation. Tol (2024), updates previous meta-studies, confirming that the economic impacts of climate change are generally negative and that poorer countries are particularly vulnerable to climate change. He also states that the impact of climate change on economic growth tends to be temporary rather than permanent. On the other hand, Stefanakis et al. (2021), discuss the potential of nature-based solutions, emphasizing their important contributions to combating climate change, improving ecosystem services, and promoting sustainable economic growth. They state that awareness should be raised and more investment should be attracted for these approaches. Raihan et al. (2022), examines how economic growth, renewable energy use, urbanization, industrialization, technological innovation, and forest areas contribute to reducing CO2 emissions and ensuring environmental sustainability in the case of Bangladesh, and offers policy recommendations for a low-carbon economy. Kiley (2024), argues that rising temperatures will have negative effects on economic growth, increasing the risk of severe economic contraction, and as a result, may have major impacts on financial stability and welfare. Conversely, Mohsin et al. (2022) argue that CO2 emissions also contribute to GDP. In addition to the climate change and economic growth relationship, other studies have focused on the link between foreign direct investment (FDI) and GDP (Pao and Tsai, 2011; Al-mulali, 2012; Gökmenoğlu and Taspinar, 2016). Pao and Tsai (2011) found evidence of unidirectional causality from output to FDI, while Al-mulali (2012) and Gökmenoğlu and Taspinar (2016) identified a long-run relationship between FDI and GDP.

The literature discussed above highlights three research gaps that need to be addressed. Firstly, the relationship between the environment and macroeconomic variables, including output volatility (OV), remains inconclusive due to mixed findings. Secondly, there is a lack of research on the impact of CO2 emissions and renewable energy on OV. Thirdly, no studies have investigated the relationship between climate change and output volatility specifically in East Asia and Pacific (EAP) countries. To address these gaps, this study aims to examine the effects of CO2 emissions, renewable energy, foreign direct investment (FDI), and trade openness on output volatility in selected EAP countries.

Theoretically, sun-spot theories claim weather conditions of the globe will be altered because of sun-spot (Jevons, 1878). Further, the theory says climate change will affect the agricultural sector and then transgress to manufacturing output, hence OV. The Environmental Kuznets Curve (EKC) hypothesis also says that environmental pollution increases in the early stages of development, subsequently the relationship between economic development and environmental pollution becomes negative, indicating a desire for higher environmental quality.

From the above mentioned theoretical and empirical studies, the study formulates four hypotheses. First, it hypothesizes that CO2 emissions increase OV. Second, it hypothesizes that renewable energy reduces OV. Third, it hypothesizes that FDI helps to lower OV. Fourth, it hypothesizes that trade openness decreases OV in the selected countries of EAP. The study employs a series of time-series models to test and validate these hypotheses.

The study makes a threefold contribution. Firstly, it addresses the limited research on the impact of environmental variables, specifically CO2 emissions and renewable energy (RE), on output volatility. By examining this relationship, the study enriches the existing literature and provides valuable insights for policymakers. It highlights the potential of minimizing CO2 emissions and increasing the use of RE to stabilize output volatility. Secondly, the study focuses on the East Asian and Pacific region, which lacks sufficient literature on this subject. This regional emphasis is significant as it offers specific guidance to policymakers in the region. By considering the unique characteristics and challenges of EAP countries, the study provides targeted recommendations for stabilizing output volatility in these areas. Lastly, the study goes beyond environmental variables and incorporates macroeconomic factors such as foreign direct investment (FDI) and trade openness. This comprehensive approach provides policymakers with a consolidated understanding of the various factors influencing output volatility. By considering both environmental and macroeconomic variables, the study offers a holistic perspective and facilitates the formulation of effective policy prescriptions.

The article has the following structure. Section II talks about data and methodology. Section III offers a summary of the empirical findings, and Section IV presents the conclusions of our study.

2. Data and Methodology

We consider five variables i.e. output volatility, trade openness, carbon emission, renewable energy, and foreign direct investment across six countries from EAP i.e. Australia, Indonesia, Japan, Malaysia, Philippines, and Singapore. The OV is constructed using a three-period standard deviation on the index of industrial production (Ramey and Ramey, 1994). Further, trade openness consists of export-import/GDP. Renewable energy consumption is the portion of renewable energy in total final energy used. Carbon dioxide emissions are those emitting from the burning of fossil fuels including manufacture of cement. Further, it includes carbon dioxide produced during the consumption of solid, liquid, and gas fuels and gas flaring. The CO2 emissions measure kg per 2015 US$ of GDP. Finally, FDI inflows to individual countries are considered for the analysis. The data set from 1990 to 2021 are extracted from the world development indicator and CEIC database based on availability. Some variables trade openness and FDI are converted to logarithmic form to detrend the series.

We then discuss the methodology. Once panel stationarity is established, we conduct cointegration and causality tests. This study's novelty lies in employing Fourier form cointegration and causality tests, relatively recent additions to the literature. Westerlund and Edgerton (2007) offered a technique that acknowledges both cross-section dependence and structural breaks in panel data. The concept of using Fourier functions in time series originates from Enders and Lee (2012), who explored them in unit root tests, while Tsong et al. (2016) extended their use to cointegration analysis. The implementation of Fourier forms, adept at identifying smooth structural shifts via trigonometric functions, into panel cointegration and causality tests is a recent development, marked around 2020-2021. Olayeni et al. (2020) probed cointegration presence in panels using Fourier functions. Concurrently, Yılancı and Görüş (2020) described the econometric basis for panel causality with Fourier functions. These methodologies consider both cross-sectional interdependencies and smooth transitional structural breaks. Fourier panel causality test is one of the most optimal causality tests to use because it takes into account both hard and soft structural breaks. Thus, it is possible to take into account factors such as economic crisis etc. that occur within the examined data range and do not cause serious changes in the data. In this way, it will be possible to avoid incorrect results that can be obtained through methods that do not take structural breaks into account.

The form of the Fourier causality test developed by Enders and Jones (2016) applied to the panels, on the other hand, was developed by Yılancı and Görüş (2020) and brought it to the literature. This method, which is the fourier form of Dumitrescu and Hurlin (2012) panel causality test, is modeled as follows:

$$y_{i,t} = \propto_i + \sum_{k=1}^{K} \gamma_i^{(k)} y_{i,t-k} + \sum_{k=1}^{K} \beta_i^{(k)} x_{i,t-k} + \delta_i \sin\left(\frac{2\pi kt}{T}\right) + \theta_i \cos\left(\frac{2\pi kt}{T}\right) + \epsilon_{i,t} \quad (1)$$

The null hypothesis of this method indicates the absence of causality in the panels, while the alternative hypothesis indicates the presence of causality.

3. Empirical Findings

In the first stage of the analysis, the presence of cross-section dependence in the panels was examined. As a result of the analysis, CDLM by Breush and Pagan (1980) and CDLMadj cross-section dependence tests by Pesaran, Ullah and Yamagata (2008) show that there is cross-section dependence in all panels.

Table 1. Cross Section Dependence Test Results

	CDLM	p-value	$CDLM_{adj}$	p-value
OV	42.42	0.00	3.65	0.00
LIIP	77.89	0.00	15.12	0.00
LTO	46.93	0.00	62.46	0.00
LFDI	31.42	0.00	41.06	0.00
RE	48.87	0.00	63.42	0.00
CO2	28.08	0.02	57.75	0.00

In the second stage of the analysis, the stationarities of the panels were examined by Pesaran's (2006) CADF panel unit root test. According to the results obtained, it is seen that all panels have unit root in level values and become stationary in different values.

Table 2. CADF Panel Unit Root Test Results

	Level	First Diff.
OV	-2.81	-6.37***
LIIP	-1.81	-4.51**
LTO	-1.84	-3.59*
LFDI	-3.17	-5.09***
RE	-1.88	-3.72*
CO2	-1.47	-3.57*

Note: Critical values are based on -4.97, -3.99 and -3.55 at 99%, 95% and 90% confidence levels. These values were obtained from Pesaran's (2006) article "A simple unit root test in the presence of cross-section dependence, Journal of Applied Econometrics, 22 (2), 265-312". ***, ** and * denote significance with 99%, 95% and 90% confidence, respectively.

In such a case where the panels are stationary in their first differences, it was deemed appropriate to use the improved version of the panel causality test developed by Dumitrescu and Hurlin (2012). The advantages of the method are that it added the Fourier forms. The results are reported in Table 3.

The causal relationships identified between lagged industrial production, output volatility, and other economic factors across different countries indicate the intricate dynamics between industrial activity and economic stability. In Japan and Malaysia, the causality from the Index of Industrial Production (IIP) to output volatility (OV), and subsequently from OV to TO, suggests that fluctuations in industrial production are a significant source of economic volatility, which then influences the countries' degree of openness to international trade. Similarly, we find the CO2 causes OV in the case of India. This finding complies with the outcome of Majeed et al. (2021). The finding that renewable energy (RE) causes OV in Australia and Malaysia may reflect the impact of transitioning towards renewable energy on the industrial sectors of these countries, potentially leading to short-term disruptions before achieving a more stable production environment.

Contrastingly, in India, foreign direct investment (FDI) is found to be a precursor to OV, implying that the influx of foreign capital can lead to economic fluctuations. This is a critical insight for policymakers who must manage the inflows of FDI to mitigate its destabilizing effects. In the Philippines, the reverse causality from OV to FDI suggests that economic volatility itself could be a factor attracting or deterring foreign investors. For Singapore, the causation from OV to RE indicates that economic fluctuations might be prompting a shift towards renewable energy, potentially as a diversification strategy to stabilize production.

Under the panel framework, the generalized causality from IIP to OV aligns with the country-specific cases of Japan and Malaysia, reinforcing the notion that industrial production levels are potent determinants of economic stability across the board. Similarly, the causality from FDI to OV is seen at the panel level, suggesting a universal trend where FDI influences economic stability. The causation from OV to trade openness may indicate that economic volatility informs countries' trade policies and their engagement with the global market. The absence of environmental factors causing OV in the panel analysis could point to a less direct or a more complex interaction between environmental policies and economic volatility, warranting further investigation to unravel these dynamics.

Table 3. Panel Fourier Causality Test Results

Causality direction	Countries	Wald stat	p-value
LIIP → OV	AUS	1.58	0.20
	IND	1.36	0.24
	JAP	**9.56*** **	**0.00**
	MAL	**4.48** **	**0.03**
	PHI	0.78	0.37
	SIN	0.12	0.72
	Panel	**2.98*** **	**0.00**
OV → LIIP	AUS	0.21	0.64
	IND	0.38	0.53
	JAP	0.76	0.38
	MAL	1.24	0.26
	PHI	1.39	0.23
	SIN	0.59	0.43
	Panel	0.76	0.68

LTO → OV	AUS	1.69	0.19
	IND	0.04	0.83
	JAP	0.10	0.74
	MAL	1.38	0.23
	PHI	0.68	0.40
	SIN	0.03	0.85
	Panel	0.65	0.55
OV → LTO	AUS	**4.15****	**0.04**
	IND	1.16	0.28
	JAP	2.89*	0.08
	MAL	4.57**	**0.03**
	PHI	0.20	0.65
	SIN	0.25	0.61
	Panel	**2.20****	**0.03**
LFDI → OV	AUS	0.40	0.52
	IND	0.08	0.77
	JAP	0.22	0.63
	MAL	0.81	0.36
	PHI	0.15	0.68
	SIN	0.51	0.47
	Panel	0.36	0.27
OV → LFDI	AUS	0.01	0.90
	IND	0.15	0.69
	JAP	0.48	0.48
	MAL	1.54	0.21
	PHI	**8.83*****	**0.00**
	SIN	1.76	0.18
	Panel	**2.13****	**0.04**
LRE → OV	AUS	**2.87****	**0.08**
	IND	1.42	0.23
	JAP	0.03	0.84
	MAL	**2.83***	**0.09**
	PHI	0.80	0.37
	SIN	1.03	0.30
	Panel	1.50	0.38
OV → LRE	AUS	1.58	0.20
	IND	1.60	0.20
	JAP	0.01	0.92
	MAL	0.23	0.62
	PHI	1.19	0.27
	SIN	**2.75***	**0.09**
	Panel	1.23	0.68
CO2 → OV	AUS	2.14	0.14
	IND	**4.37****	**0.03**
	JAP	0.01	0.91
	MAL	0.28	0.59
	PHI	1.89	0.16
	SIN	0.08	0.77
	Panel	1.46	0.41
OV → CO2	AUS	0.85	0.35
	IND	0.02	0.87
	JAP	0.37	0.53
	MAL	0.41	0.52
	PHI	0.52	0.46
	SIN	0.05	0.81
	Panel	0.37	0.28

Note: *** and ** denote significance with 99% and 95% confidence, respectively.

4. Conclusion Remarks

The investigation into the causal links between industrial production, output volatility, and various economic indicators reveals key insights into the economic dynamics of different nations, with implications for policy-making. The observed causality from the Index of Industrial Production (IIP) to output volatility (OV) in Japan and Malaysia, and subsequently from OV to long-term trade openness (LTO), underscores industrial activity as a core driver of economic fluctuations, which then impacts these countries' engagement in global trade. This pattern necessitates careful monitoring and management of industrial output by policymakers to foster economic stability and devise trade policies that can absorb and adapt to such volatility.

In the context of renewable energy (RE), its influence on OV in Australia and Malaysia signifies the economic repercussions of shifting towards greener energy sources, presenting an immediate challenge for industrial sectors. Policy implications here would involve structuring transition policies that can mitigate the adverse effects on output volatility while harnessing the long-term benefits of sustainable energy.

The contrasting directions of causality between FDI and OV in India and the Philippines highlight the need for nuanced FDI policies that recognize the dual role of foreign investments as both a catalyst for and a respondent to economic stability. Policymakers should construct regulatory frameworks that stabilize FDI flows and output volatility to ensure economic growth without undue oscillations.

Singapore's shift towards renewable energy in response to OV points to the strategic role renewable investments can play in economic stabilization. Policymakers should thus consider encouraging renewable energy development as part of a broader strategy to buffer against economic volatility.

Overall, the absence of a direct causality from environmental factors to OV in the panel analysis suggests that environmental policies may not have immediate, discernible effects on economic volatility. Policymakers should recognize the complex interplay between environmental factors and economic performance, necessitating comprehensive, long-term strategies to integrate environmental considerations seamlessly with economic objectives.

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