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Investigating the impacts of technological innovation and renewable energy on environmental pollution in countries selected by the International Renewable Energy Agency: A quantile regression approach

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ABSTRACT

Investigating the factors affecting CO_2 emissions has always been a challenge. One problem with existing studies is that these studies have been relied on mean-based regression approaches, such as ordinary least squares (OLS) or instrumental variables, which implicitly assumes that the impact of variables along the distribution of CO_2 emissions is the same. Unlike previous studies, the present study will use the quantile regression developed by Koenker & Bassett, which is not limited to the assumption. So that, the purpose of this study is to investigate the impacts of technological innovation and renewable energy on CO_2 emissions in selected countries of the International Renewable Energy Agency (IRENA) using quantile regression over the period 1990-2016. The results of this study exhibited that the impact of renewable energy on CO_2 emissions was negative and statistically significant. This impact is also enhanced in high quantiles (countries with high pollution). In all the studied quantiles, the impact of technological innovations on CO_2 emissions was positive, significant and initially decreasing, while increasing again over time. The results of the symmetry test also indicated that by increasing in the volume of CO_2 emissions, the variable impact of renewable energy upraised. However, no incremental trend was observed in innovation.

Key words: Technological innovation, Renewable energy, Environmental pollution, Quantile.

INTRODUCTION

Climate change is one of the biggest threats to achieve sustainable development (De Jesus 2013). The subject of climate change and global warming has been due to the deterioration of environmental quality because of the expansion of economic activity in the last century (Lau *et al.* 2010). In recent years, environmental issues have been incorporated into policy decisions, particularly those related to growth and development policies. Natural resources have been considered as inputs for production and environmental quality as a measure of well-being. The relevance of environmental issues to economic variables as well as development theories and experiences has been extensively studied (Valeria 2006). When the flow of renewable resources into the economic cycle exceeds the rate of renewal, it reduces the productivity of the resources and increases the probability of their extinction. The release of waste over the environmental capacity increases the likelihood of erosion of natural resources. The reduction and rapid erosion of end-use resources will increase the utilization of renewable resources. Also, increased release

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of waste over the environmental capacity, generally indicates that the economy is moving towards greater dependence on the environment (Hung & Saw 2000). The expansion of economic activity and the emission of greenhouse gases have doubled the need for renewable energy sources and new technological innovations to control environmental pollution. Renewable energy has been cited as one of the major factors of production, so that along with other factors of production, it has a decisive role in the economic life of countries. So that, by the development and progress of economy, its importance has increasingly been elevated. The increasing dependence of human life on electricity has made this sector potentially play a significant role in the functioning of the various economic sectors in the countries (Sadorsky 2010). Challenging approaches to the impact of technological innovation on the environment have also been taking place in recent years.

The endogenous growth literature exhibits that technological innovation can have a positive impact on the environment in the long run. According to economists, who agree with this view, technological innovation leads to increased investment directly and indirectly through lower costs of information and transactions, elevated productivity of production factors, upraised savings and improved resource allocation, thereby resulting in positive impacts on the environment. Contrary to this view, some economists believe that technological innovation can harm the environment. They argue that if technological innovation improves the resource allocation and thus improves savings efficiency, the savings rate may be reduced. So, it leads to a credit crisis and damages the environment by reducing the investment (Dogan 2016). Environmental pollution is one of the most challenging topics in today's world. Many scholars have discussed this issue. Different methods, approaches and examples have yielded conflicting results, and investigations in this area are continued. So that, the purpose of this study is to investigate the impacts of technological innovation and renewable energy on environmental pollution in selected countries of the International Renewable Energy Agency (IRENA) using quantile regression over the period 1990-2016.

Theoretical Literature

One of the main causes of global warming is the emission of greenhouse gases. The emission amounts of these gases are directly related to the energy consumption of countries, while energy is one of the factors in the production and economic growth. Therefore, the control of pollutant emissions slows the growth of countries. The broad array of economic factors affecting CO_2 emissions includes the energy consumption, foreign trade, production, investment, financial development and population as follows:

Ecological economists such as Ayres & Nair (2008) pointed out that in the biophysical model of growth, energy is the single most important growth factor. So that, labor and capital are intermediary factors that need energy to be employed. While, in the view of some neoclassical economists, such as Berndt & Denison (2011), energy has an indirect impact on economic growth through its impact on labor and capital, but does not directly affect economic growth. They believe that energy is an intermediate input, hence the basic factors of production are only labor, capital, and land. However, the excessive consumption of energy, especially fossil fuels, to achieve economic growth, has elevated environmental pollution. Non-renewable energy is consumed in human daily activities, but burning large quantities of energy increases CO_2 in the atmosphere. Over 3 billion tons of CO_2 are released annually due to the burning of non-renewable energy, which significantly are not recyclable and remain in the atmosphere for a long time, thereby leading to global warming. The global air temperature has risen by 1.02 °C during the years 1900-2015. This increase in temperature has caused climate change. The natural disaster caused by climate change can cause human injury and death. Reports suggest that if humans do nothing about the emission of greenhouse gases, by 2030, the global average temperature is likely to rise to 4 °C (Binaysa 2014). The environmental consequences of global warming, climate change and the emission of greenhouse gases have raised concerns about the use of non-renewable energy, such that the public interest in using renewable energy has become more widespread. The major features of renewable energy include reduced CO_2 emissions and help to

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protect the environment. The consumption of renewable energy can alleviate growing concerns about the emission of greenhouse gases, high prices, volatile energy and dependence on external energy sources (Khoshnevis Yazdi & Shakouri 2017). In international trade, countries also seek strategic policies to achieve their business goals. The initial belief is that adopting rigorous environmental policies will reduce the competitiveness of firms in the country. However, in practice, these policies have improved the performance of companies in some countries and have created competitive advantage for them. Also, expanding trade and increasing in competitive pressures between domestic firms and foreign competitors will lead to a softened environmental policies and delay in adopting national environmental laws in the face of the free trade process as well as upraised emission of greenhouse gases (Panayotou 1999). On the other hand, the population growth, poverty and environmental degradation in developing countries have created a vicious cycle. This cycle has severely affected the people's quality of life and has neutralized efforts of developing countries to achieve sustainable development. In general, population pressure leads to environmental degradation and poverty exhibiting unpleasant impacts on the environment. This overwhelming population growth through factors such as the expansion of public transport and upraised energy consumption increases CO_2 emissions. Given that in new approaches to growth, economies have largely shifted from factor-driven growth to growth based on technological innovation. So, examining the effects of these technological changes on the environment is an attractive topic for some authors (Zhang & Cheng 2009; Wang *et al.* 2017; Yu & Du 2018). The impact of technological innovation on CO_2 emissions at various levels of economic development is different (Fan *et al.* 2006). It is shown that technical innovations play an important role in reducing fossil fuels (Tang & ton 2013).

Some researchers have reported that R&D spending has made a positive impact on economic growth (Fang 2011; Lotz 2015). Investing in R&D and technological change can reduce CO_2 emissions (Jones 2002). Therefore, technological innovations play an important role in reducing the energy consumption and improving the energy efficiency (Sohag & Begum 2015). In the opposite approach, growth models are also used to illustrate the impact of innovation on CO_2 emissions, because innovation indirectly impacts the emission of greenhouse gases through increased production, capital and energy consumption (Kumar *et al.* 2012).

Financial development leads to economic growth through the impacts of level and efficiency with increased investment. The impact of level suggests that the optimal financial system shifts resources from inefficient to efficient projects. The impact of efficiency suggests that financial development is a good way to increase liquidity and diversify assets to allocate funds to profitable projects. An increase in investment leads to economic growth by elevating domestic production, hence an upraised economic growth increases the demand for energy. Increasing demand for energy sources could provide the basis for more emission of greenhouse gases (Zang et al.2017).

Experimental studies

Halkos & Tzeremes (2009), using the Generalized Method of Moments (GMM), investigated the Kuznets relationship between the environmental performance of countries and the national income of 17 OECD countries over the period 1980-2002. they conclude that there is no correlation similar to the Kuznets curve (Inverted-U shape nonlinear relationship) between environmental efficiency and income. Abdouli (2016) examined the impact of economic growth, direct investment inflows, open trade, and energy consumption on the environment in 17 MENA countries using static and dynamic panel data methods over the period 1990-2013. The results displayed that there is an environmental Kuznets curve. It was also found that foreign direct investment increases environmental pollution, thereafter, the energy consumption elevates CO_2 emissions.

In a study, Yu & Du (2018) examined the impact of technological innovation on CO_2 emissions in China over the period 1997-2015. Furthermore, the CO_2 trend was predicted for the period 2016-2030. The results of this study exhibited that technological innovation is an effective factor in reducing the emission of greenhouse gases. According to other results, the CO_2 trend will

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decrease over the forecast period to 2030, due to technological growth and stricter environmental laws. (World bank report). Torabi *et al.* (2015) investigated the impact of energy consumption, economic growth and foreign trade on the emission of greenhouse gases in Iran by ARDL approach over the period 1981-2013. Their results exhibited that the energy consumption per capita, the real GDP per capita and the degree of openness of economy had a positive and significant impact on CO_2 emissions per capita. It was also found that the imbalance in the level of CO_2 emissions after about two years is moderated by changes in the energy consumption, GDP and the degree of openness of the economy. Adinehvand (2016) also investigated the impact of foreign direct investment and open trade on CO_2 emissions in OPEC member countries over the period 2020-2000, using the Johansen method and vector error correction model, displaying that the foreign direct investment and trade liberalization had positive impacts on air pollution in both Iran and Venezuela. Lotfali Pour & Bastam (2017) studied the impacts of economic growth and urbanization on CO_2 emissions in Asian countries. The STRIPAT model framework was employed for the test, and the parametric and quasi-parametric models of panel data were estimated with fixed impacts for 22 Asian countries over the period 2000-2014. Their results indicated that the parametric panel data method did not confirm the existence of inverted-U shape relationship for both models. However, by employing the quasi-parametric panel data method, the EKC hypothesis was only confirmed the variables of economic growth and CO_2 emissions.

MATERIALS AND METHODS

Previous studies have used standard methods (such as Ordinary Least Squares, Instrumental Variables, and Generalized Method of Moments), which explain the average impact of explanatory variables on the overall distribution of the dependent variable. In the present study, the quantile regression method, first introduced by Koenker & Bassett (1974) and developed in subsequent studies (Koenker & Machado 1999; Koenker& Hallock,2001), will be used to investigate the factors contributing to the emission of greenhouse gases. This method gradually became a comprehensive method for statistical analysis of linear and nonlinear response variable models in different fields.

The main impetus for applying quantile regression is to provide a model with a detailed and comprehensive look at response variable estimation to allow for independent variables to be included, not only in the data center of gravity, but in all parts of the distribution, especially in the beginning and end sequences. Also, this method does not have the limitations of the assumptions of ordinary regression, the heterogeneity variance, and the influential presence of outliers in estimating the coefficients. This method has two main advantages in estimating the factors affecting CO_2 emissions. Compared to ordinary least squares (OLS) regression, it is more robust than outliers and abnormal distribution, and it is also possible to estimate the impact of effective factors at different CO_2 distribution points (Koenker & Hallock 2001). Quantile regression can be expressed as relation 1:

$$q\left(\frac{CO_{2it}}{\Omega_t}\right) = \theta_{0t} + \theta_{1t}NRE_{it} + \theta_{2t}RE_{it} + \theta_{3t}CR_{it} + \theta_{4t}Tr_{it} + \theta_{5t}POP_{it} + \theta_{6t}PGDP_{it} + \theta_{7t}Fina_{it} + \theta_{8t}FDI_{it} + \mu_{it} \quad \textbf{(1)}$$

In relation 1, $q\left(\frac{CO_{2it}}{\Omega_t}\right)$ is the Conditional Quantile of CO_2 and Ω_t contains the information at time t. Relation 1 can be rewritten as relation 2:

$$CO2_{it} = +X_{it}\theta_t + \varepsilon_{it} \quad \textbf{(2)}$$

In relation 2, X represents a spectrum of variables affecting CO_2. Unlike the OLS method which is based on minimizing the sum of squares of residuals, the quantile method uses the minimization of the sum of the absolute values of the residuals to estimate the pattern parameter (Koenker & Machado 1999). It is also referred to as Least Absolute Deviations (LAD) as follow:

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$$\operatorname*{Min}_{\theta}\left[\sum_{y_{it}\geq x_{it}\theta_{\tau}}\tau\left|y_{it}-x_{it}\theta_{\tau}\right|+\sum_{y_{it}\leq x_{it}\theta_{\tau}}(1-\tau)\left|y_{it}-x_{it}\theta_{\tau}\right|\right]=\min_{\theta}\sum_{t=1}^{T}\varphi_{\tau}\left(y_{it}-x_{it}\theta_{\tau}\right)$$

A description of the variables presented in relation 1 is shown in Table 1:

Table 1. The list of variables and their sources.

Variable	The Definition of Variable	Source
Carbon dioxide (CO_2) emissions	Total CO_2 due to energy consumption	EIA (2019)
Per capita GDP (PGDP)	Real GDP per capita	WDI (2018)
Foreign Direct Investment (FDI)	Net foreign direct investment inflow as a percentage of GDP	WDI (2018)
Foreign Trade (TR)	Trade in percentage of GDP	WDI (2018)
Technological Innovation Index (CR)	Technological innovation index	WDI (2018)
(Non-Renewable) Energy Consumption (NRE)	Total primary energy consumption (Oil, Gas, Coal) (Non-Renewable)	BP-statistical review (2019)
Total Renewable Energy Consumption (RE)	Total consumption of renewable energy	BP-statistical
Financial Development (Fina)	Credits to the private sector as a percentage of GDP	WDI (2018)
Total Population (POP)	Population size (n)	WDI (2018)

The samplings

The examined samples in this study included 30 countries selected from the International Renewable Energy Agency (IRENA) countries from 1990 to 2016. The list of countries is as follows:

Table 2. The list of the studied countries.

Greece	France	Germany	Japan	Thailand	Mexico
Iceland	Sweden	Portugal	Malaysia	Egypt	Argentina
Ireland	Denmark	India	Iran	Russia	Philippines
Spain	Norway	Bangladesh	Turkey	England	Peru
Italy	Finland	China	Indonesia	Netherlands	America

Static Variables

Specific tests of this type of data can be used to check the reliability of variables in the combined data. Here we use the Levin-Lin-Chu test (LLC), which is more applicable to the investigation of static variables in the combined data. The H0 hypothesis test indicates the existence of a single root for each variable. If the calculated probability is less than 5%, the hypothesis of the existence a single root for that variable is rejected. The results of the static test of variables are shown in Table 3. According to the results of the Levin-Lin-Chu test, only the FDI and TR variables are static, while the other variables are static with one-time difference. Since some research variables are static and others are non-static, therefore, it is necessary to perform a co-integration test before estimating the model to avoid false regression estimation. The results of the co-integration test are presented in Table 4 indicating the rejection of the null hypothesis of non-co-integration in the Kao and Fisher co-integration tests. Therefore, the co-integrating relationship in the estimation model is accepted. The results of the quantile regression estimation are presented in Table 5. Based on the estimation results in different quantiles, the impact of PGDP on CO_2 emission has been positive. The strong impact of economic growth on CO_2 emissions from low-emission countries is reduced to high-emission countries. By using more CO_2 emissions, economic growth has less impact. There are two important reasons for this phenomenon. Firstly, for high-emission countries with a more developed economy, government environmental laws will be improved and secondly, economic growth requires the energy consumption. Thus, a low-carbon model reduces the contradiction between pollution and economic growth. Foreign investment also had a significant negative impact on CO_2 emissions in the lower quintiles, while exhibited a significant impact in the high quintiles.

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Table 3. The results of static testing of variables by Levin-Lin-Chu test (Level and First Difference).

Variables	Level / First difference	Static test	Probability	Static or Non-static
CO_2	Level	2.47	0.99	Non-static
	Difference	-21.47	0.00	Static
PGDP	Level	20.001	1.00	Non-static
	Difference	-9.050	0.00	Static
FDI	Level	-6.57	0.00	Static
	Difference	-	-	-
TR	Level	-2.34	0.00	Static
	Difference	-	-	-
CR	Level	14.39	1.00	Non-static
	Difference	-16.60	0.00	Static
NRE	Level	6.21	1.00	Non-static
	Difference	-18.34	0.00	Static
RE	Level	13.31	1.00	Non-static
	Difference	-5.36	0.00	Static
POP	Level	-1.09	0.13	Non-static
	Difference	-11.73	0.00	Static
FINA	Level	-1.40	0.07	Non-static
	Difference	-6.65	0.00	Static

Source: Results of the present study.

The impact of foreign trade on CO_2 emission in different quintiles was positive and significant, but the impact was upraised in higher quintiles. Similar results have been obtained concerning to the impact of technological innovations on CO_2 emissions. So that all the studied quintiles had a positive and significant impact, initially decreasing but increasing again over time. Technological innovation allows the introduction of new capital goods, which may play a greater role in production than in existing capital goods. Because the product is a function of different types of capital goods and energy, hence, technological innovation and R&D create side impacts on science and knowledge. Therefore, it can be said that R&D has a significant positive impact on CO_2 emissions through the creation of new goods, increased demand for energy inputs and greater use of natural resources. The impact of non-renewable energy on CO_2 emissions has always been significantly positive in all the studied quintiles and exhibited the highest coefficient of estimation in the studied coefficients. Furthermore, the impact of non-renewable energy on the high quintiles was higher than on the low quintiles. The impact of renewable energy on CO_2 emissions was also significantly negative. Thus, in countries with high emissions, the impact of the consumption of non-renewable energy on CO_2 emissions is stronger than in those with low emissions. The impact of the consumption of renewable energy on CO_2 emissions is greater when the emission level is lower. Therefore, in high-emission countries, the energy consumption structure is still important. The impact of population on CO_2 emissions in the studied quantiles was small, but significantly positive, indicating the role of economic activities in CO_2 emissions. At the end, the impact of financial development on the primary quantiles has been positive, but over time the impact on the high quantiles has changed negatively. Fig. 1 also illustrates the alterations in the regression coefficients of different quantiles for the independent variables. Next, through the test of Newey and Powel (1987), the symmetry for the studied quantiles is calculated in Table 6.

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Table 4. The results of the Kao and Fisher co-integration test.

Kao Co-integration Test				
	Test statistic		Probability	
	-3.30		0.00	
Fisher co-integration Test				
Hypothesis	**Test statistic**	**Probability**	**Fisher maximum eigenvalues of test statistic**	**Probability**
no co-integration relationship (co-IR)	31.88	0.00	31.88	0.00
A max. of 1 co-IR	20.79	0.99	168.2	0.00
״ ״ 2 ״ ״	372.6	0.00	372.6	0.00
״ ״ 3 ״ ״	1239.0	0.00	684.2	0.00
״ ״ 4 ״ ״	865.9	0.00	451.7	0.00
״ ״ 5 ״ ״	588.1	0.00	299.0	0.00
״ ״ 6 ״ ״	383.2	0.00	217.1	0.00
״ ״ 7 ״ ״	240.0	0.00	190.0	0.00
״ ״ 8 ״ ״	140.3	0.00	140.3	0.00

Source: Results of the present study.

Table 5. Results obtained from the estimation of quantile regression.

Variable	Q10	Q20	Q30	Q40	Q50	Q60	Q70	Q80	Q90
PGDP	0.0013 (2.97)	0.0010 (7.13)	0.0086 (13.66)	0.00079 (13.45)	0.00046 (2.34)	0.00024 (2.37)	0.00109 (12.64)	0.00109 (14.42)	0.0012 (3.81)
FDI	-0.928 (-1.85)	-1.99 (-2.75)	-1.82 (-3.71)	-1.60 (-7.47)	-0.79 (-0.66)	0.109 (0.71)	-0.050 (-0.376)	-0.058 (-0.543)	0.376 (0.756)
TR	0.080 (0.69)	0.377 (10.73)	0.0063 (2.98)	0.349 (9.18)	0.145 (5.32)	0.030 (2.55)	0.043 (3.71)	0.234 (15.73)	0.772 (12.55)
CR	0.0083 (5.99)	0.0076 (8.44)	0.0056 (6.50)	0.0036 (7.30)	0.0026 (5.47)	0.0024 (4.53)	0.0022 (4.70)	0.0019 (4.67)	0.0088 (2.64)
NRE	1.032 (9.49)	1.204 (8.03)	1.52 (10.26)	1.85 (30.35)	1.99 (30.35)	2.05 (36.32)	2.12 (38.23)	2.16 (46.33)	1.415 (3.22)
RE	0.738 (0.162)	-3.30 (-2.15)	-3.88 (-2.98)	-3.75 (-3.91)	-3.03 (-2.96)	-4.93 (-4.55)	-6.53 (-8.57)	-6.76 (-8.99)	-2.99 (1.38)
POP	0.000167 (0.45)	0.000343 (8.49)	0.000293 (6.67)	0.000223 (9.06)	0.000208 (9.90)	0.000202 (11.92)	0.000185 (11.99)	0.000172 (13.55)	0.000283 (4.02)
FINA	0.247 (3.84)	0.286 (6.34)	0.223 (5.27)	0.151 (4.03)	0.057 (0.972)	-0.0347 (-1.43)	-0.096 (-4.83)	-0.0824 (-5.38)	-0.354 (-1.73)

Table 6. The symmetry results for the quantities examined.

	Technological Innovation (CR)		**Renewable Energy (RE)**	
	Statistic	**Probability**	**Statistic**	**Probability**
0.1 - 0.9	0.011	0.00	28.82	0.09
0.2 - 0.8	0.004	0.00	-0.947	0.73
0.3 - 0.7	0.0028	0.00	-2.391	0.084
0.4 - 0.6	0.00046	0.18	-1.270	0.09

Source: Results of the present study.

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With respect to the computational probability value, in the studied quantiles, for technological innovation, the null hypothesis, i.e. the results are symmetric, is rejected. In other words, by increasing the volume of CO_2 emissions, the variable impact of technological innovation has not been elevated. Inverse results are obtained for the variable of renewable energy. It was also found that in the studied quantiles, for renewable energy, the null hypothesis, i.e. the results are symmetric, is confirmed. So, by increasing in the volume of CO_2 emissions, the variable impact of renewable energy has been raised.

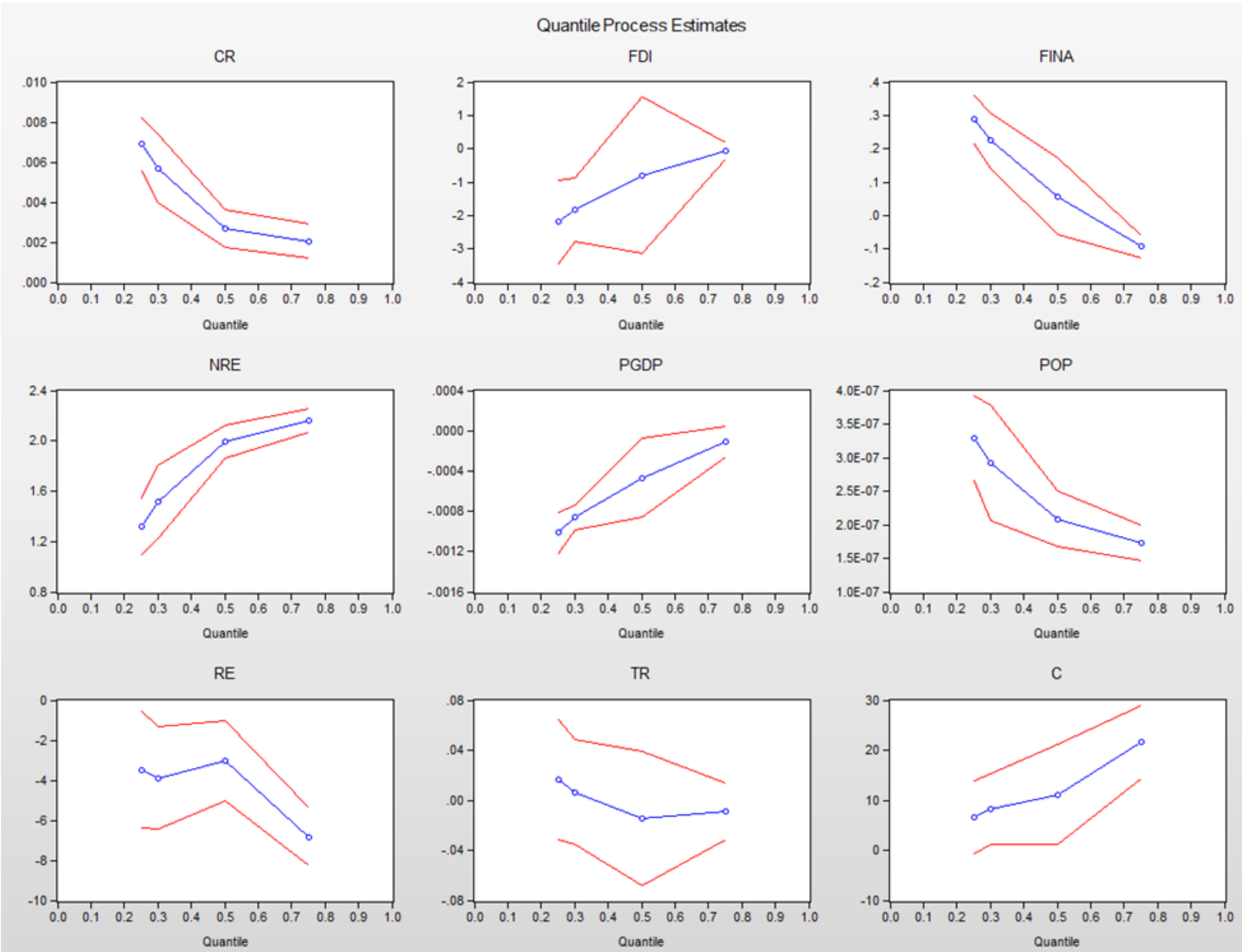

Fig. 1. Changes in quantile regression coefficients for independent variables.

CONCLUSION

The role of the environment in sustainable development is of particular importance. The concept of sustainable development has so far been used in various ways in a variety of concepts. Behind this concept lies the fact that development must be without damaging the environment and with preserving resources for further generations. Many studies have therefore examined the role of economic activities in the emission of greenhouse gases. Conditional mean-based regression methods are used to investigate the factors affecting CO_2 emissions, but since the reaction of the variables may have an asymmetric distribution and change in reaction speed, methods that focus only on conditional mean are not very creditworthy. Quantile regression has largely solved this problem by examining the impacts of variables in different quantiles .which was also used in the present study. The results exhibit that non-renewable energy consumption, technological innovation and real per-capita income in all the studied quantiles had a significant and positive impact on CO_2 emissions. These findings indicate how important the energy consumption and income may be, suggesting that the policies to conserve energy resources in economies with less pollution may be more beneficial to the environment.

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The impact of renewable energy on CO_2 emissions was also statistically negative. This impact is also enhanced in high quintiles. The results also suggest that countries with higher CO_2 production should adopt stricter environmental and energy policies, increased infrastructure for energy efficiency, and improve employing alternative energy sources, which are relatively free of pollutants, to lower their carbon footprint.

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بررسی تأثیرات نوآوری فنی و انرژی‌های تجدیدپذیر بر آلودگی محیط زیست در کشورهای منتخب آژانس بین‌المللی انرژی‌های تجدید پذیر: رویکرد رگرسیون کوانتایل

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چکیده

بررسی عوامل موثر بر انتشار دی‌اکسید کربن همواره چالش‌برانگیز بوده است. یکی از مشکلات مطالعات موجود این است که این مطالعات به رویکردهای رگرسیون مبتنی بر میانگین مانند حداقل مربعات معمولی (OLS) یا متغیرهای ابزاری اعتماد کرده‌اند که به طور ضمنی فرض می‌کند که تأثیر متغیرها در طول توزیع انتشار دی اکسید کربن یکسان است. برخلاف مطالعات پیشین، در این مطالعه از رگرسیون کوانتایل توسعه داده شده توسط کوینکر و باست استفاده خواهد شد، که محدود به فرض نخواهد بود. با توجه به این موضوع هدف این مطالعه بررسی تأثیرات نوآوری فنی و انرژی های تجدید پذیر بر انتشار دی اکسید کربن در کشورهای منتخب آژانس بین المللی انرژی های تجدید پذیر (IRENA) با استفاده از رگرسیون کوانتایل طی دوره زمانی ۲۰۱۶-۱۹۹۰ است. نتایج این مطالعه نشان داد که اثر انرژی‌های تجدیدپذیر بر انتشار CO_2 نیز منفی و از لحاظ آماری معنی‌دار بوده است. این اثر همچنین در کوانتایل-های بالا (کشورهای با آلودگی بالا) تقویت نیز شده است. در زمینه تاثیر نوآوری‌های فنی بر انتشار CO_2 در تمامی کوانتایل‌های مورد بررسی تأثیر مثبت و معنی‌دار بوده است که در ابتدا روندی کاهشی داشته اما به مرور دوباره روند افزایشی داشته است. نتایج آزمون تقارن نیز نشان داد با افزایش حجم انتشار CO_2، اثر متغیر انرژی‌های تجدیدپذیر افزایش یافته است، اما برای نوآوری روند افزایشی مشاهده نشده است.

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