Analyzing Technology-Emissions Association in Top-10 Polluted MENA Countries: How to Ascertain Sustainable Development by Quantile Modeling Approach

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Abstract: This study investigates the relationship between technological progression and ambient air pollution in top-10 polluted Middle East and North African (MENA) countries by using monthly data for the period of 1990-2017. The Quantile cointegration proposed by Xiao (2009), Quantile-on-Quantile regression (QQ) proposed by Sim and Zhou (2015), and Quantile Autoregressive Granger causality developed by Troster (2018) are applied. In particular, we examine to which extent, quantiles of technological progression affect the quantiles of ambient air pollution, by developing separate indicators for both the mentioned aspects using Principal Component Analysis (PCA). Our empirical findings unfold mutual dependence between technological progression and ambient air pollution. Furthermore, the results of Quantile Autoregressive Granger causality test conclude a bidirectional causal relationship between technological progression and ambient air pollution.

Keywords: Technological progression; Air pollution; Quantile modeling; MENA countries

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1. Introduction

With the progression in time, nations are achieving economic growth by bringing forth the innovations in their production processes. These innovations are allowing the nations to achieve the economic growth through maximum utilization of the available resources. In the regime of Sustainable Development Goals (SDGs) by the United Nations, the role of innovations is gaining more prominence than before. By means of 17 objectives, SDGs are targeted at improving the standard of living of people by devising policies for sustainable development, and by the end of 2030, the nations across the globe are expected to fulfill these goals. Now, innovation plays a major role in attaining these objectives, as innovation might allow the nations to achieve decent economic growth, clean and affordable energy, and will help them in fighting the climatic shift. Once the nations are able to achieve these objectives, they will be able to attain several other SDG objectives, as the SDGs are integrated in nature. However, various groups of countries are failing to in several fronts for attaining these goals and one of such groups of countries is the Middle East and North African (MENA) countries. The MENA countries first came into limelight by not signing the Kyoto Protocol. Owing to the dependence on hydrocarbon resources, MENA countries are struggling to bring down the climatic issues. In 2015 COP21 summit, the agreements made for the MENA countries entail several issues regarding their shortcomings in addressing the climatic shift issues (Babiker, 2016). One of the reasons behind these issues is the failure to diffuse the innovations across the member nations, and researchers have identified several reasons for the same (e.g., Sabry, 2018; Saidi et al., 2019; Tagliapietra, 2019). In order to assess these issues at a deeper level, the COP22 summit was organized in Morocco during November 2016, and the major focus of this summit was to look into the governance-climatic shift nexus, with special attention on the MENA countries.

The MENA countries are characterized by high growth potential, while causing substantial ambient air pollution by means of its growth trajectory. During 2017, the CO_2 emissions of the MENA countries amount to 7.33 per cent of global CO_2 emissions, while they contribute to nearly 4 per cent of the global GDP (World Bank, 2018). Moreover, the growth trajectory attained by the MENA countries is proving to be unsustainable, as the innovations carried out in these nations are unable to cater to the equitable economic growth (Omar, 2019; Shahbaz et al., 2019). In a recent press release, the UNICEF has mentioned about the critical state of education of children and employment of the youth in the MENA countries (UNICEF, 2019). In such a situation, achievement of the full potential of innovation might not be possible for these nations. Owing to this problem, technological innovations in these nations are not getting diffused across the borders, and within the nation, as well. So, from economic perspective, the role of innovations needs to be rediscovered.

When we talk about the role of innovation from economic perspective, it needs to be remembered that the economic growth of the MENA countries are largely dependent on the fossil fuel-based energy solutions. Following the “Limits to Growth” approach, it can be said that the economic growth pattern in these nations is constrained and unsustainable (Meadows, 1974). There are two reasons behind such a claim: (a) the continuous dependence on fossil fuel-based solutions results in faster depletion of the natural resources with higher economic growth rate, and (b) combustion of fossil fuel-based solutions create ambient air pollution, which can possibly have a negative consequence of the hygienic state of the labor force. Henceforth, in order to sustain the economic growth pattern by reducing the dependence on fossil fuel-based energy solutions, the MENA countries need to look for alternate energy solutions and innovation can be their possible vehicle in this pursuit. During COP21 summit, this is one of the major areas, which was the point of discussion for the MENA countries. If the recent SDG progress reports published by EDA (2019) and Göll (2019), then it can be seen that the MENA countries have performed poorly in attaining the objectives of SDG 9 (Industry, Innovation, and Infrastructure), SDG 13 (Climate Action), SDG 7 (Affordable and Clean Energy), SDG 11 (Responsible Consumption and Production), and several others. This status of attaining SDG objectives divulges the policy level inefficacy present in the MENA countries. In order to ascertain sustainable development, these nations need to align their innovation and energy policies with the SDG objectives first, so that the other allied policies can be subsequently aligned, in line with these two policies. However, in order to align these two policies, it is necessary to cognize the possible association between technological progression and ambient air pollution in these nations. A proper policy alignment might help in building a multipronged SDG framework to address the overall sustainable development issues being cropped up in the MENA countries. However, without having the requisite knowledge on the associative directions between them, it might not be possible to prescribe the innovation and energy policies suitably.

Taking a cue from this discussion, we can derive the objective of the present study. In this study, we plan to assess the association between technological progression and environmental quality for top-10 polluting MENA countries over the period of 1990-2017. As our intention is to prescribe policies regarding innovation and energy consumption, so we need to choose a set of sample countries, which are the worst hit due the irregularities of these two policies. In order to ascertain sustainable development in these nations, choosing the most polluted countries might provide us with the perspectives those will help us in generalizing the policies for the countries, which are better-off than the chosen sample, at least in ecological terms. Based on the results of this study, we intend to design a policy framework for addressing the SDGs, and in order to complement the policy framework, we will further try to align the innovation and energy policies, followed by allied economic and developmental policies. This aspect has been largely ignored by the existing literature of environmental economics, and this study contributes to the literature by assessing the association between technological progression and environmental quality, from the perspective of ascertaining the sustainable development in the MENA countries. The theoretical contribution of this study lies in designing a multipronged SDG framework by analyzing the association between technological progression and environmental quality. Compared to the extant literature on this aspect, this study differentiates itself by widening the policy-level approach within the SDG framework, and thereby, providing policymakers a wide range of solutions, which has been discussed in the extant literature with a narrow unilateral policy-level focus.

On the other hand, this study has a contribution in terms of the methodological application by complementing the theoretical and policy-level contribution. In this study, we employ the advanced quantile methods, i.e. Quantile cointegration (Xiao, 2009), Quantile-on-Quantile regression (Sim and Zhou, 2015), and Quantile Autoregressive Granger causality (Troster, 2018). These methods are capable of assessing the association among the variables across the quantiles of the variables, and therefore, we will be able to assess the impact of the entire quantile distribution of one variable on the quantile distribution of the other variable. While designing a robust policy, it is beneficial to analyze the entire spectrums of the target and control policy parameters, and there lies the advantage of this particular methodological adaptation. These estimation methods allow to analyze the impact of the control policy parameter on the target policy parameter across the quantiles, and thereby, allowing to understand the level of policy enforcement to be imposed at various levels (Chang et al., 2020; Sharif et al., 2020). These methods have several advantages over the traditional unit root, cointegration, and causality tests, in terms of the explanatory power of the tests, and for producing the estimates free from serial correlation and heteroskedasticity. Apart from this aspect, the literature has produced the results by considering individual variables, and we believe that considering single variables or assigning equal weight to the variables might not produce fruitful results for any context. A single variable might not be capable of depicting the contextual scenario, and the factors contained by any contextual scenario might not have equal impact on the contextual development. Owing to these reasons, we have considered CO_2 emissions, Methane (CH_4) emissions, Nitrous Oxide (N_2O) emissions, PM2.5 emissions, and other greenhouse gas emissions as the indicators of environmental quality, and number of patent and trademark applications, number of researchers, technical cooperation grants, and public expenditure in R&D as the indicators of technological progression. Based on these variables, we have developed two indices for environmental quality and technological progression by using Principal Component Analysis (PCA), and have used them in the analysis. Inclusion of these indices has given us the flexibility to depict the contextual scenario in a much detailed manner, and therefore, the expected test outcomes might be able to divulge the nearly true consequences in the top-10 polluted MENA countries. This approach might be considered as the methodological contribution of the study.

Rest of the paper is designed in the following manner: section 2 deliberates the review of the relevant literature, section 3 talks about the methodological applications, section 4 comments on the results obtained from the empirical exercise, and section 5 concludes the study, along with possible policy recommendations.

2. Literature Review

Technological Innovation has been a major catalyst of development since the beginning of civilization. Innovation and technological advancements have significant effects on society and they can prove to be crucial for achieving sustainable development goals (Yuan and Zhang, 2020). The role of innovation capacity of a country is reflected not only in catalyzing the achievement of economic progress, but also in demonstrating significant impact on the environmental quality (Haščič et al., 2012; Shahbaz et al., 2018; Shahbaz and Sinha, 2019).

Following this, two broad strands of literature have been developed over the years in analyzing the relationship between environmental quality and innovation. First strand deals with the impact of technological innovation on environmental quality, whereas the second strand deals with the impact of energy innovation on environmental quality. We will present these two strands in subsequent sub-sections.

2.1. Technological Innovation and Environment

Various measures of technological innovation have been adopted by scholars in order to assess the impact of technology on environment. For example, Dauda et al. (2019) used total trademark application to examine the effects of innovation along with economic growth on CO_2 emissions for three regions, i.e. the G6 countries, the MENA countries, and the BRICS countries. The study found that innovation deteriorates environmental quality for the MENA and BRICS countries, whereas the improvement can be found only in case of the G6 countries. The rationale behind such outcome can be attributed to different stages of development, and this statement has been reinstated in the work of Albino et al. (2014). On the other hand, Cheng et al. (2019) analyzed the impact of environmental patents on per capita CO_2 emissions for the BRIICS (Brazil, Russia, India, Indonesia, China, and South

Africa) countries. In their analysis, they used panel fixed effect quantile regression method suggested by Koenker (2004), and the results obtained by them revealed that environmental patents cause increase in CO_2 emissions. This particular issue has been attributed to the lack of necessary legislation and policies to improve eco efficiency and allowing environmental patents to be applied in the secondary sectors. Due to its advantage over traditional models, quantile regression approach was also applied by Sinha et al. (2020) in order to explore the impact of technological progression on ambient air pollution for the N11 countries. The results obtained by them demonstrated that ambient air pollution is negatively affected by technological progression for low and medium quantiles but positively affected for higher quantiles.

Analyzing 27 OECD countries over the period of 1990-2015, Danish et al. (2019) found that investment in research and development (R&D) lowers CO_2 emissions from transport sector. A more substantial approach regarding OECD countries' CO_2 emission level was done by Ganda (2019), who used a variety of indicators for innovation and technology, e.g. number of researchers, triadic family patents, renewable energy consumption, and R&D spending. They found that not all measures of innovation have similar effects in reducing CO_2 emissions. Although renewable energy consumption and R&D spending help to reduce CO_2 emissions, patent family and number of researchers found to have positive relationship with CO_2 emissions. In another study on OECD countries, Hashmi and Alam (2019) concluded that these economies should choose to implement green technology rather than continuing traditional manufacturing technologies in reducing CO_2 emissions. Mensah et al. (2018) investigated individual OECD countries (28 countries) to see the effect of innovation on CO_2 emissions over 1990-2014. In particular, they developed the ICC (Innovation Claudia Curve) theory of innovation, which states that there exists an inverted U-shaped relationship between emission and innovation. CO_2 initially increases with innovations, and beyond a certain level, technological spillover comes into play to reduce emissions. Results from STIRPAT model asserted that environmental quality can be improved via per capita R&D investment in 9 out of 28 countries, and it worsened due to R&D activities only in 3 countries. In a subsequent study, Mensah et al. (2019) used two different indicators for innovation, i.e. trademark application and climate change related patent, to examine their impacts on environment for OECD countries. The findings revealed that both the indicators help in reducing emissions.

While talking about indicators of innovation, it is required to mention the work of Can and Gozgor (2017), who used economic complexity indicator as a measure of technological progress, as R&D expenditures alone cannot cater to growth, and thereby, making it an inapt measurement of innovation. Moreover, economic complexity is an indicator of structural transformation which has the capability of transforming an economy from energy intensive to Technology intensive country. Using DOLS estimates for France, the study found that a higher rate of economic complexity is associated with lower level of CO_2 emission. This result was further confirmed by Shahbaz et al. (2018), who also found that innovation leads to an improvement in environmental quality in France. In another study, Dogan et al. (2019) analyzed the impact of economic complexity on CO_2 emissions in 55 countries over 1971-2014. They categorized their sample into lower income, higher middle income, and higher income groups. They found that economic complexity decreases CO_2 emissions only in countries with higher income bracket, but in other two groups, economic complexity contributes positively towards CO_2 emission.

2.2. Energy Innovation and Environment

Another strand of research has examined the effect of energy innovation on environment. Whenever it comes to innovation, researchers have focused more on energy innovation as a tool to encounter global warming, compared to technological innovation, in general (Jin et al., 2017). Energy innovation can help in achieving emission reduction and attaining energy conservation agenda (Lin and Zhu, 2019), which can be considered crucial in order to achieve competitive advantage (Lee and Lee, 2013).

Given the importance of energy innovation, Kucak and Ulucak (2019) investigated the effects of R&D expenditures in energy sector on per capita CO_2 emission in high-income OECD countries. In this study, they considered five indicators of energy R&D expenditures, namely (a) fossil fuel R&D, (b) renewable energy R&D, (c) energy efficiency R&D, (d) nuclear energy R&D and (e) other power and storage R&D. By means of GMM estimators, they found that energy efficiency R&D and fossil fuel R&D have boosting effect on CO_2 emissions. Since most of the OECD countries depend on fossil fuel consumption, the study could not provide any significant relationship between R&D expenditure on renewable energy and CO_2 emissions, R&D expenditures on nuclear energy and CO_2 emissions. The study found also that energy storage innovation has a highly significant negative effect on CO_2 emissions. Alvarez et al. (2017) used public budget on energy research development and demonstration as a measure of energy innovation, and they found a direct relationship between increased energy innovation and reduced GHG emission. However, it was also found that it might take two years for the measures related to energy innovation to become fully efficient, and therefore, efforts on energy R&D do not have any short-term effects.

Lin and Zhu (2019) examined how renewable energy technology innovation can help in reducing CO_2 emissions in China. From panel threshold model proposed by Hansen (1999), they found that the effect of innovation varies across provinces with different energy structures. In another study, Du et al. (2019) explored how green technology innovation affects CO_2 emissions at various levels of income for a total of 71 countries. In doing so, they found that green technology innovations contribute much in mitigating the effect of CO_2 emissions only for countries with the income above a certain threshold point, specifically 34,694.078 US dollars (2011 price level). This implies that green technology innovations have very low effect on reducing CO_2 in underdeveloped economies, owing to high cost of implementation (Song et al., 2019).

Even though it is generally believed that energy innovation helps to reduce environmental degradation, the “Energy Rebound Effect” introduced by Khazzoom (1980) has questioned the validity of this claim. The rationale behind this effect is that improvements in energy efficiency through technological progress may change relative price of energy services, and falling price of energy services increases energy demand and consequential energy consumption (Gillingham et al., 2016). “Thus on the net basis technological progress negatively influences the effectiveness of energy efficiency and environment sustainable policies” (Alvi et al., 2018). This effect was empirically tested by Gu et al. (2019) for China to analyze whether improvements in energy technology can help the country achieve carbon emission efficiency, or not. Energy technological progress was measured by energy technological patent data. They found that there is an inverted U-shaped relationship between energy technological progress and CO_2, and thereby implying that environmental quality in China starts to increase with technological progress only after reaching a certain turning point. Lotz (2018) on the other hand, found the validity of this effect for South Africa during 2008-2014. In another study, using spatial econometric model, Wang et al. (2019) analyzed whether technological progress (measured by energy patent) can effectively reduce CO_2 in

Chinese regions. They found that technological progress has statistically negative significant effect on reducing carbon emissions. Moreover, the study concluded that if emission reduction technology is not properly identified, then the rebound effect of CO_2 might not be avoided.

Our study contributes to the extant literature of innovation-environment nexus in several ways. First, most of the previous studies on innovation-environment nexus have undertaken single indicators of environmental quality and technological progression. The present study uses Principal Component Analysis (PCA) to create two separate indices for both the mentioned aspects, as an index can capture multiple dimensions of a concept (Babbie, 2005). Therefore, indices can give policymakers and general audience an effective way to compare complex dimensions (OECD, 2008). Second, according to Gjoksi (2011), it is very difficult to capture the interface between innovation and sustainable development since they share facets not only with each other but also with other policy areas. Our study examines this issue of sustainability and innovation from environmental perspective and tries to develop an understanding in this regard. In view of the SDGs, this association can draw paramount attention of the policymakers, and there lies the contribution of this study.

3. Methodology and data

We divide the section into three parts by applying a set of methods in our analysis. The first part explains whether the variable follow unit root in different procedures. In the second part, we use the quantile autoregression unit root test to test whether quantiles of the distribution follow a unit root process (Koenker and Machado, 1999). We then use the linear cointegration test to check and establish the cointegration relationship among variables (Johansen, 1991). By applying the quantile cointegration test by Xiao (2009), we test the null hypothesis of constant cointegration test. We then conclude our methods section by applying the granger causality in quantiles (Troster, 2018). The detail of methodological schema is provided in Supplementary Materials 1.

3.1. Theoretical framework

Industrial development depends on several factors, out of which innovation is a prime factor. Innovation helps the industrial sector to maximize the return on investment, by allowing the maximum utilization of the natural resources. There are several ways, in which an industry can foster innovation. One of the most popular ways is to protect the innovative ideas and solutions, and therefore, patent and trademark applications can cater as the indictor of innovation (Amato and Beolchini, 2018; Demirel et al., 2018). On the other hand, it might also be possible that the technological innovation is being promoted by the policymakers, and therefore, they invest in R&D activities. In such a scenario, the government expenditure can be another indicator of innovation (Pang et al., 2019). It might also be possible that the industrial sectors might extend their support in promoting the R&D activities within the boundary of a particular nation, and this financial support is recognized in the form of technical corporation grants. This grant can be another measure of innovation, as this grant has been channelized to foster innovation (Dost et al., 2019). In all the cases, innovation might not be possible in absence of researchers, and therefore, presence of researchers in a country can be another indicator of innovation (Mikulčić et al., 2020).

Saying this, it also needs to be remembered that the innovations in these nations are directed towards bringing the most out the consumption of natural resources, which is the primary driver of economic growth in these nations. However, in the due course of natural resource consumption, several ambient air pollutants are generated. Now, it can be assumed that the pollutants present in the ambient atmosphere can possibly have a far-reaching impact on the hygienic state of the citizens, and that can be determined by the half-life of the ambient air pollutants (Kim et al., 2019; Sinha and Sengupta, 2019). Based on this assessment, we have chosen carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), particulate matter (PM2.5), and other greenhouse gases. Going by this criterion, we have excluded sulphur dioxide and other oxides of nitrogen from our analysis (Sinha and Bhattacharya, 2016, 2017). These ambient pollutants are hypothesized to rise with the rise in the capacity of technological innovation of a nation.

In view of this, the theoretical model of the study can be written as per the following:

$$ENV_{i,t} = f(TECH_{i,t})$$

Where, *TECH* is the indicator of technological innovation, *ENV* is the indicator of environmental degradation, *i* is the 10 MENA countries, and *t* is the study period.

3.2. Data description

In this study, we have utilized the annual data for top-10 polluted MENA countries, i.e. Bahrain, Iran, Iraq, Israel, Kuwait, Libya, Oman, Qatar, Saudi Arabia, and the United Arab Emirates, over the period of 1990-2017. Following Shahbaz et al. (2019) and Sharif et al. (2020), annual data for all the countries have been transformed into monthly data using quadratic match-sum method. Data for all the variables have been collected from World Development Indicators (World Bank, 2018). The data source and variable descriptions are mentioned in Supplementary Materials 2. In this study, we have formulated the index for innovation using number of patent (PAT) and trademark (TM) applications, number of researchers (RES), technical cooperation grants (GR), and R&D expenditure by government (GOVEX). Similarly, environmental index has been formed using CO_2, CH_4, N_2O, PM2.5, and other greenhouse gas emissions (GHGo). In both the cases, we have utilized principal component analysis (PCA). Therefore, the technological innovation (TECH) and environmental degradation (ENV) indices can be written as:

$$TECH_{it} = f(PAT_{it}, TM_{it}, RES_{it}, GR_{it}, GOVEX_{it}) \tag{23}$$

$$ENV_{it} = f(CO_{2_{it}}, CH_{4_{it}}, N_2O_{it}, PM2.5_{it}, GHG_{O_{it}}) \tag{24}$$

Where, i is the countries, and t is the years under consideration. Results of the PCA are outlines in Supplementary Materials 3.

4. Analysis of results

As a beginning point of the analysis, we have investigated the unit root properties of the model parameters. In this pursuit, we have carried out Augmented Dickey-Fuller (Dickey and Fuller, 1979) and Phillips-Perron (Phillips and Perron, 1988) unit root tests. The empirical outcomes of these tests are recorded in Table 1. The results indicate that both the variables are non-stationary at the level. However, both of the variables, i.e. technological innovation and environmental degradation indices exhibit stationarity after first difference. In order to bring additional insights to this analysis, we have carried out quantile autoregressive unit root test by Koenker and Xiao (2004) on the first differentiated variables. The empirical outcome recorded in Supplementary Materials 4 includes the persistence estimates $\alpha(\tau)$ at 0.05-0.95 quantiles, and the corresponding t-statistics. The results indicate that across all the quantiles, both of the variables exhibit stationarity after first difference. With a view to circumventing the possibilities of serial correlation, 10 lags of the first derivative of the dependent variable have been considered. The t-statistics in Supplementary Materials 4 denote the rejection of non-stationarity hypothesis at 1% level of significance. This outcome confirms that both the model parameters are first order integrated. This integration property is demonstrated across the selected 10 MENA countries under consideration.

<Place for Table 1>

After confirming the integration property of the model parameters, we will move towards estimating their long run associative properties. In this pursuit, we have employed Johansen (1991, 1995) cointegration test. The trace and maximum eigenvalue statistics reported in Table 2 exhibit that the technological innovation and environmental degradation indices are significantly cointegrated for all the 10 MENA countries. In order to look deeper into the cointegrating association, we have carried out the quantile cointegration test by Xiao (2009). This test is aimed at investigating whether the cointegrating association changes across the quantile distribution, and henceforth, it is applied across the quantile distribution. The test outcomes recorded in Table 3 exhibit the presence of non-linear cointegrating association among the model parameters, whereas the Johansen cointegration test confirmed about the linear association.

<Place for Table 2>
<Place for Table 3>

Upon confirming the presence of long run cointegrating association among technological innovation and environmental degradation indices, we need to assess the nature of long run association between them. In this pursuit, we have employed the quantile-on-quantile regression (QQR) approach devised by Sim and Zhou (2015). The test outcome recorded in Figure 1 exhibit the nature of the slope of the regression line, denoted by $\varphi(\lambda, \tau)$. This particular slope unveils the impact of the τ^{th} quantile of technological innovation index on the λ^{th} quantile of environmental degradation index, and vice versa. The test outcome demonstrates the diversity in the association between technological innovation and environmental degradation indices across the 10 MENA countries (Full result is available at Supplementary Materials 5). We will now discuss the test outcome for these countries.

Let us start with Bahrain. For **Bahrain**, impact of technological innovation on environmental degradation is high at the lower quantiles. However, as we move up the quantiles, this impact seems to be exhibiting a diminishing trend. Between 0.85-0.95 quantile, this impact tends to be zero. On the other hand, impact of environmental degradation on technological innovation is exhibiting an upward trend. This growth trend is visible between 0.05-0.65 quantiles and beyond 0.65 quantile, this trend tend to be linear to unity. This exhibits the efficacy of the technological innovation in bringing down the level of environmental degradation, and the consequential rise in the demand of technological innovation for betterment of environmental quality. This rise in the demand might be seen as the demand of renewable energy solutions, as this might reflect the pro-development agenda of the policymakers in Bahrain. This segment of results falls contradicts the findings of Omri (2013), where the author found energy-led economic growth to have increased the CO_2 emissions. Moreover, this result might also be considered as an extension of the finding of Alnaser (2015). Now, in case of **Iran**, impact of technological innovation on environmental degradation is negative across the quantiles. However, from quantile 0.35, the impact is showing the sign of diminishing, and thereby indicating the fall in the effectiveness of technological innovation in controlling the environmental degradation. In such a scenario, the demand for technological innovation for emission reduction will start rising at the higher quantiles, and this particular behavior is exhibited in the impact of environmental degradation on technological innovation. Since quantile 0.55, the impact has been found to be positive, and thereby exhibiting the need of technological innovation with the rise in environmental degradation. This particular segment of the results addresses the policy gap identified by Hosseini et al. (2019) for Iran. Moreover, the EKC analysis of Moghadam and Dehbashi (2018) also demonstrates in policy-level ineffectiveness of Iran in controlling environmental degradation, where the emission levels are high, and thereby revealing unsustainable nature of the economic growth pattern. Our results for Iran support this finding.

We will now look into the case of **Iraq**. Till quantile 0.60, impact of technological innovation on environmental degradation is found to be negative. Beyond this quantile, this very impact turned to be positive, and thereby, demonstrating the environmental policies to be ineffective at the higher quantiles of environmental degradation. Due to the ecologically positive impact of technological innovation, its demand can be expected at the lower quantiles. However, with the progression along the quantiles, the demand of the technological innovation further falls, and it is visible in the impact of environmental degradation on technological innovation. This shows that the technological innovation has not been diffused uniformly throughout the provinces in Iraq, and therefore, the positive externality of the technological innovation is not visible, especially in the high emission regions. The results for the higher quantiles fall in the similar lines with the findings of Shuai et al. (2017), who found the energy intensity, as the proxy of technological innovation, catalyzes the CO_2 emissions in Iraq. However, for the remaining quantiles, the results fall in the similar lines with the findings of Du et al. (2019) for Iraq. For **Israel**, the impact of technological innovation on environmental degradation is steadily rising with the progression in the quantiles. The economic growth pattern in Israel is leading towards environmental degradation through technological innovation, and that's why it can be expected that the consequential environmental pressure might lead towards the rise in the demand for technological innovation in pursuit of renewable energy solutions. Rising impact of environmental degradation on technological innovation supports this argument. This shows that the technological innovation being carried out in Israel and being demanded by the citizens are different, as the objective of technological innovation is different from demand side to supply side. This segment of the results extends the finding of Magazzino (2015) by the substituting economic growth by driver of economic growth.

The scenario for **Kuwait** is not much different from that of Israel. Impact of technological innovation on environmental degradation shows a rising trend along the quantiles, which signifies the negative environmental externality created by the technology-driven economic growth. Now, in such a situation, the demand of environment-friendly technologies should rise along with the rise in environmental degradation. This rise in the demand for innovative green technological solutions is depicted in the rising impact of environmental degradation on technological innovation. This segment of results shows the demand-supply gap regarding the technologically improved solution for the sustainable development of the nation. The results of Wasti and Zaidi (2020) can be extended in this segment of the findings, where one of the drivers of economic growth is found to have a negative environmental impact through ambient air pollution. This discussion also reflects the findings of Gelan (2018), who mulled over the removal of harmful energy subsidies to have a control over the CO_2 emissions in Kuwait, and thereby, creating a basis for ecological sustainability. For **Libya**, the technological innovation is found to have negative impact on environmental degradation. From quantile 0.15, the negative impact is found to be steadily rising. Thereby, it can be assumed that innovation-led economic growth pattern is exerting positive environmental externality by causing reduction in the environmental degradation. This particular situation might be a consequence of the negative impact of environmental degradation on the innovation-led economic growth, and this situation is visible in the negative impact of environmental degradation on technological innovation. This negative impact is consistent across all quantiles. This segment of the results reflects the findings of Belgasim et al. (2018) and Destek (2019), who found the potential of renewable and technologically improved solutions for the improvement of environmental quality in Libya. A similar kind of scenario can be seen in case of **Oman**, where the impact of technological innovation has been environment-friendly. Between 0.05-0.45 quantiles, the impact is gradually falling, steady between 0.45-0.60 quantiles, increased between 0.60-0.58 quantiles, and then dropped. When the economic growth pattern can internalize the negative externalities, then demand for technological innovation might rise with the emissions level. This is visible in the impact of environmental degradation on technological innovations, and this impact is steadily rising across the progression in quantiles. This segment of results falls in the similar lines with the findings of Alalouch et al. (2019), who identified the factors responsible for green construction, and thereby preparing the basis for the sustainable development in Oman. The extension of this result can be found in the works of Gorus and Aydin (2019), who obtained the similar findings in frequency domain.

For **Qatar**, the impact of technological innovation on environmental degradation is low till quantile 0.85 and the impact suddenly increased beyond this quantile. It has shown that at the higher levels of emission, technological innovation turns out to be ineffective and exerting negative environmental externality. In such a scenario, the demand for environment-friendly innovation is expected to rise at its higher quantiles. This scenario is visible in the impact of environmental degradation on technological innovation, which has demonstrated steady rise between 0.15-0.85 quantiles, and then shown sudden rise. It gives an indication regarding the unsustainable economic growth pattern and the environmental awareness coexisting in Qatar. Al-Marri et al. (2018) had shown this within the context of renewable energy awareness in Qatar, and this result complements our findings. In case of **Saudi Arabia**, the impact of technological innovation on environmental degradation is showing a downward trend along the progression of quantiles, and a consequential rise in the demand of environment-friendly technologies can be visualized through the rising impact of environmental degradation on the technological innovation. The assessment of Dehwah et al. (2018) regarding the diffusion of energy-efficient buildings in Saudi Arabia gives the indication towards the complementarity of our findings. A similar kind of scenario can be seen for the **UAE**. Direction and movement of both the impacts fall in the similar lines with that of the case of Saudi Arabia, and thereby exhibiting the demand for eco-friendly technological innovations in the UAE. The predicted energy mix for the UAE assessed by Said et al. (2018) gives an indication towards the energy security and clean energy future of this nation. Our results comply with this finding.

<Place for Figure 1>

In order to bring forth robustness to the QQ regression analysis, we have adopted the quantile regression approach, and the plots of the slope coefficient are depicted in Supplementary Materials 6. A comparison between Supplementary Materials 5 and 6 demonstrates that the coefficients obtained by means of these two approaches exhibit almost similar kind of movement across the quantiles. Although the magnitude of the coefficients differ in these two approaches, the directional association among the model parameters show the robustness of the results obtained through QQ regression analysis. As the quantile regression estimates are decomposed by QQ regression approach, therefore, the slope estimates of quantile regression can work as suitable check of robustness for the QQ regression approach.

Two-way directionality is an inherent feature of any sustainable policy design, and there are several evidences in the literature to support this argument. In this pursuit, we employ the Granger causality analysis over quantiles by Troster (2018). These estimates are robust to various conditions of quantile auto regressive model postulating the hypothesis of Granger causality. Test outcome are recorded in Appendix 7. Apart from the median quantile, bidirectional causal association is visible between technological innovation and environmental degradation for the 10 MENA countries under consideration, and this association is significant at 1% level for all the cases. From policymaking perspective, these causal associations might bring forth several insights for these countries. Now, while literature talks about the causal association between the air pollutants and economic growth, the drivers of economic growth are chosen to be energy consumption, financial development, trade openness, and several others. The evidences of conservation and feedback hypotheses are chosen with a view to compare the results obtained by us. The results obtained by Bekhet et al. (2017) show that the feedback hypothesis holds true for the UAE, Oman, and Kuwait considering financial development-CO_2 emissions nexus, for Oman, Kuwait, and Bahrain considering economic growth-CO_2 emissions nexus, and for Oman considering energy consumption-CO_2 emissions nexus. For urbanization-CO_2 emissions nexus, Abdouli and Hammami (2017) found the evidence of conservation hypothesis for Iran, Kuwait, Libya, Qatar, and Saudi Arabia. In this study, we have contributed to the literature of environmental economics by demonstrating the evidence of feedback hypothesis for technological innovation-environmental degradation nexus.

5. Concluding remarks and policy implications

This study looked into the association between technological innovation and environmental degradation in top 10 polluted MENA countries over the period of 1990-2017. In this pursuit, we have developed technological innovation index using (a) R&D expenditure as percentage of GDP, (b) number of patent applications, (c) number of trademark applications, (d) technical cooperation grants, and (e) number of researchers per million population, and environmental degradation index using (a) CO_2 emissions, (b) methane emissions, (c) nitrous oxide emissions, (d) PM2.5 emissions and (e) other greenhouse gas emissions. Subsequent to that, we have employed quantile modeling approach, including QQ regression approach by Sim and Zhou (2015) and quantile autoregressive Granger causality approach by Troster (2018). The results obtained from the empirical exercise gave us several insights on existing policy perspectives and possible sustainable development in these nations.

Economic growth pattern of these nations are enabled by technological innovation, and in order to boost economic growth, environmental protection has been given lower preference. Though it might give these nations a short run gain, but in the long run this growth trajectory might face issues regarding the sustainability. These sustainability issues might come in the economic, environmental, and social forms, and therefore, the policies might be designed keeping these issues into consideration. Encouraging innovation for achieving the economic growth might not be inclusive, as the negative externalities caused by this growth pattern are not internalized by the existing policy directives. With the rise in technological innovation, these nations might experience high industrial growth, at the cost of environmental quality. With the rise in income, the existing pool of natural resources will start to diminish, and the inequality in terms of per capita availability of resources might start rising (Sinha et al., 2018, 2019). This inequality is necessarily translated from the income inequality, which might be a result of the economic growth pattern. Hence, the consequential inequality in the economic system might bring forth social imbalance, which have hindrance on the economic growth pattern. On the other hand, rising environmental degradation might have a deteriorating impact on the hygienic state of the labor force, and that will also have hindrance on the economic growth pattern. With passage of time, these issues might be complemented by the issue of energy efficiency. Therefore, the existing policies in these nations need to be revisited in light of the evidences found in this study.

While carrying out the policy level modifications, it needs to be remembered that while internalizing the negative externalities, economic growth trajectory should not be affected. Therefore, the policies need to be designed at several stages and with a particular set of target sector at every stage (Roy and Singh, 2017; Roy et al., 2020). While allocating fund for technological innovations, the policymakers might also invest towards the discovery of alternate and clean energy solutions. Now, in this process the fiscal balance of the nation might be lessened, and in order to cover this short run loss, the policymakers should introduce pollution tax mechanism. The financial institutions might be instructed to provide the loans and advances to the industrial players against the interest rates evaluated against the amount of environmental degradation created by those firms, i.e. interest rates will be higher for the firms with more level of pollution. In this way, the firms will be gradually demotivated to use the environmental deteriorating technologies in the production processes. This move by the policymakers might be able to reduce the demand for outdated and environmental deteriorating technologies, and import of such technologies will be gradually substituted by the endogenously designed technologies.

While saying this, it should also be remembered that this particular move might also cause short run economic losses, as the cost of production of the industries might rise owing to the technological transition (Zafar et al., 2019). In such a situation, the policymakers should stress on creating new vocation opportunities, which will be driven by technological advancement towards clean and renewable energy solutions. This policy-level initiative will have several positive impacts on the economy. When the demand for outdated and environmental deteriorating technologies will go down, it can be assumed that the demand for the traditional fossil fuel will also consequently reduce. This might create an unemployment problem in the mining sector, and this problem might create several social imbalances within the nation. A section of the unemployed labors might be absorbed in the newly created green technological initiatives, and thereby, the unemployment pressure on the economy can be reduced to some extent. Secondly, the green initiatives will be adding to the national income through output creation and income generation. Therefore, the economic loss being incurred by the existing firms will be partially covered up by these green technological initiatives. Lastly, these initiatives will be having very less or no negative externality on the environmental quality, and thereby, they will help in ascertaining the ecological balance.

Now, in order to have a smooth implementation of these policy measures, the citizens should be aware of environmental protection. Creating awareness among citizens should be carried out through institutionalization, and this can take place through modifications of educational curriculums. With the continuous modifications of educational curriculums, the policymakers will be able to create environmental awareness at the grassroots level, and this might also be able to institutionalize the innovations for environmental protection. When these policies will be implemented, the demand for clean and green energy solutions might rise, as the level of environmental awareness will increase among the citizens. This complete circle of the policy level implementations might able to bring out the positive externalities in terms of sustainable development in the top 10 polluted MENA countries, out of the causal associations found between technological innovation and environmental degradation. In doing so, policymakers will be able to provide less-expensive green energy solutions, quality education, stable and eco-friendly vocational prospects, sustainable consumption pattern, and stable social order. Further study on this aspect can be carried out by considering sector-level energy efficiency and other dimensions of social developments in emerging economies.

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Table 1: Variable description

Variables	*Description*	*Source of data*	*Reference study*
CO_2	CO_2 emissions in thousand metric tons	World Development Indicator (World Bank, 2018)	Roberts et al. (2019)
CH_4	CH_4 emissions in thousand metric tons of CO_2 equivalent	World Development Indicator (World Bank, 2018)	Yusuf et al. (2012)
N_2O	N_2O emissions in thousand metric tons of CO_2 equivalent	World Development Indicator (World Bank, 2018)	Sinha and Sengupta (2019)
PM2.5	mean annual exposure of PM2.5 emissions in $\mu g/m^3$	World Development Indicator (World Bank, 2018)	Dong et al. (2018)
GHG_O	other greenhouse gas emissions (i.e. HFC, PFC and SF_6) in thousand metric tons of CO_2 equivalent	World Development Indicator (World Bank, 2018)	Mallapragada et al. (2018)
PAT	number of patent applications	World Development Indicator (World Bank, 2018)	Lemus and Marshall (2018)
TM	number of trademark applications	World Development Indicator (World Bank, 2018)	Hidalgo and Gabaly (2012)
RES	number of researchers in R&D per million people	World Development Indicator (World Bank, 2018)	De Rassenfosse and de la Potterie (2009)
GR	technical cooperation grants in current USD	World Development Indicator (World Bank, 2018)	Bojnec (2011)
GOVEX	R&D expenditure as a percentage of GDP	World Development Indicator (World Bank, 2018)	Vicente and Lopez (2006)

Table 2: Results of traditional unit root tests

Test	**Countries**	**TECH**		**ENV**		**Countries**	**TECH**		**ENV**	
		Level	**First Diff.**	**Level**	**First Diff.**		**Level**	**First Diff.**	**Level**	**First Diff.**
ADF	Bahrain	-1.438	-13.927[a]	-0.424	-9.438[a]	Libya	0.090	-12.824[a]	-2.564	-13.065[a]
	Iran	2.907	-13.102[a]	-1.488	-12.602[a]	Oman	-2.211	-13.696[a]	0.493	-10.853[a]
	Iraq	-3.077	-14.110[a]	-1.415	-12.961[a]	Qatar	-2.723	-13.755[a]	-0.720	-13.747[a]
	Israel	-0.868	-10.993[a]	-0.530	-10.668[a]	Saudi Arabia	0.169	-12.043[a]	-1.473	-12.162[a]
	Kuwait	0.087	-11.121[a]	-1.544	-11.224[a]	UAE	-1.085	-13.519[a]	0.223	-11.959[a]
PP	Bahrain	-1.929	-14.516[a]	-0.460	-9.459[a]	Libya	0.692	-13.257[a]	-2.893	-13.725[a]
	Iran	1.419	-13.820[a]	-1.121	-13.357[a]	Oman	-3.377	-14.322[a]	0.004	-11.556[a]
	Iraq	-2.931	-14.667[a]	-1.493	-13.694[a]	Qatar	-2.616	-14.377[a]	-0.859	-14.373[a]
	Israel	-1.009	-11.710[a]	-0.631	-11.348[a]	Saudi Arabia	-0.616	-12.822[a]	-1.940	-12.802[a]
	Kuwait	-0.135	-11.861[a]	-1.195	-11.964[a]	UAE	-2.014	-14.172[a]	-0.599	-12.700[a]

a is significant value at 1%

Table 3: Quantile Autoregressive Unit Root test

Quantile	TECH		ENV		TECH		ENV		TECH		ENV		TECH		ENV		TECH		ENV	
	α(τ)	t-stats	α(τ)	t-stats	α(τ)	t-stats	α(τ)	t-stats	α(τ)	t-stats	α(τ)	t-stats	α(τ)	t-stats	α(τ)	t-stats	α(τ)	t-stats	α(τ)	t-stats
	Bahrain				**Iran**				**Iraq**				**Israel**				**Kuwait**			
0.05	0.600	**-2.116**	0.802	**-0.816**	0.816	**-0.675**	0.666	**-1.350**	0.030	-4.514	0.038	-5.721	0.833	**-1.151**	0.172	**-0.175**	0.830	**-0.710**	0.144	**-0.378**
0.10	0.661	-2.655	0.872	**-1.654**	0.889	**-1.823**	0.732	**-2.036**	0.030	-4.539	0.037	-2.725	0.760	**-2.344**	0.172	**-0.328**	0.943	**-0.683**	0.144	**-0.971**
0.15	0.659	-4.161	0.969	**-0.703**	0.934	**-1.338**	0.876	**-1.690**	0.030	-7.238	0.037	**-0.540**	0.912	**-1.050**	0.172	**-1.202**	0.955	**-2.636**	0.144	**-0.923**
0.20	0.762	-3.514	0.983	**-0.511**	0.967	**-0.811**	0.925	**-1.969**	0.030	**-1.707**	0.068	**-0.135**	0.953	**-0.818**	0.171	**-0.432**	0.959	-9.160	0.144	**-1.053**
0.25	0.851	-3.404	0.988	**-0.758**	0.988	**-0.459**	0.948	**-1.987**	0.030	**-1.359**	0.114	**-0.109**	0.951	**-1.112**	0.171	**-0.458**	0.962	-16.359	0.143	**-0.908**
0.30	0.891	-3.231	0.991	**-1.123**	0.985	**-0.931**	0.962	**-2.599**	0.030	**-0.410**	0.175	**-0.107**	0.948	**-1.920**	0.214	**-0.094**	0.965	-21.960	0.143	**-0.839**
0.35	0.900	-4.221	0.999	**-0.250**	0.980	**-1.827**	0.970	**-2.774**	0.050	**-0.326**	0.495	**-0.064**	0.946	**-2.820**	0.230	**-0.085**	0.966	-24.740	0.143	**-0.229**
0.40	0.904	-4.969	1.000	**0.079**	0.983	**-2.243**	0.973	-3.036	0.050	**-0.279**	0.495	**-0.067**	0.928	-4.632	0.241	**-0.083**	0.967	-23.699	0.143	**-0.175**
0.45	0.916	-5.179	1.001	**0.270**	0.980	-3.661	0.979	**-2.387**	0.080	**-0.171**	0.494	**-0.061**	0.906	-7.213	0.478	**-0.056**	0.967	-18.426	0.143	**-0.142**
0.50	0.900	-6.405	0.993	**-1.353**	0.976	-5.163	0.974	-3.295	0.171	**-0.128**	0.494	**-0.067**	0.913	-6.705	0.682	**-0.034**	0.967	-16.012	0.462	**-0.086**
0.55	0.892	-6.470	1.004	**0.890**	0.969	-5.359	0.951	-5.200	0.185	**-0.119**	0.534	**-0.114**	0.908	-7.539	0.680	**-0.032**	0.965	-13.709	0.460	**-0.083**
0.60	0.887	-5.970	1.008	**1.485**	0.959	-5.647	0.954	-3.838	0.193	**-0.106**	0.533	**-0.106**	0.910	-7.146	0.731	**-0.027**	0.970	-9.183	0.732	**-0.037**
0.65	0.923	-3.267	1.008	**1.404**	0.961	-4.558	0.948	-3.958	0.341	**-0.080**	0.648	**-0.073**	0.900	-6.354	0.737	**-0.030**	0.976	-5.201	0.833	**-0.022**
0.70	0.902	-3.429	1.001	**0.159**	0.960	-2.739	0.945	-3.702	0.427	**-0.061**	0.647	**-0.070**	0.863	-9.380	0.809	**-0.016**	0.980	**-2.297**	0.878	**-0.021**
0.75	0.871	-3.298	0.995	**-0.388**	0.974	**-1.401**	0.954	**-2.361**	0.448	**-0.031**	0.699	**-0.026**	0.857	-6.365	0.885	**-0.007**	0.981	**-1.687**	0.927	**-0.014**
0.80	0.827	-3.567	0.999	**-0.044**	0.958	**-1.509**	0.928	**-1.901**	0.489	**-0.022**	0.720	**-0.024**	0.806	-5.495	1.122	**0.003**	0.982	**-1.075**	1.061	**0.009**
0.85	0.782	**-2.381**	0.993	**-0.109**	0.923	**-1.640**	0.864	**-1.882**	0.606	**-0.011**	0.767	**-0.010**	0.782	**-2.214**	1.270	**0.005**	0.950	**-1.580**	1.109	**0.008**
0.90	0.727	**-1.773**	0.963	**-0.321**	0.873	**-1.636**	0.786	**-1.629**	1.516	**0.005**	1.224	**0.002**	0.750	**-2.045**	2.069	**0.009**	0.917	**-1.366**	1.321	**0.003**
0.95	0.713	**-1.141**	0.711	**-1.592**	0.867	**-0.639**	0.661	**-1.255**	2.160	**0.001**	1.174	**0.001**	0.705	**-1.487**	3.281	**0.012**	0.851	**-0.635**	1.890	**0.006**
	Libya				**Oman**				**Qatar**				**Saudi Arabia**				**UAE**			
0.05	0.157	**-0.255**	0.816	**-0.768**	0.774	**-1.942**	0.768	**-1.515**	-0.155	**-0.007**	0.734	**-1.124**	0.753	**-1.831**	0.414	**-2.262**	0.243	**-0.001**	0.672	**-1.046**
0.10	0.156	**-0.474**	0.683	**-2.066**	0.805	-2.762	0.845	**-1.304**	-0.171	**-0.015**	0.640	**-2.694**	0.833	**-2.314**	0.597	-2.776	0.255	**-0.022**	0.843	**-1.288**
0.15	0.162	**-2.343**	0.696	-2.812	0.804	-3.722	0.871	**-2.084**	-0.174	**-0.042**	0.712	-3.415	0.894	**-2.352**	0.724	-3.034	0.266	**-0.034**	0.953	**-0.569**
0.20	0.162	**-2.207**	0.750	-3.926	0.871	-3.055	0.959	**-0.924**	-0.175	**-0.082**	0.810	-3.233	0.950	**-1.673**	0.817	-3.480	0.272	**-0.044**	0.983	**-0.348**
0.25	0.167	**-0.942**	0.802	-3.848	0.911	-2.776	0.974	**-0.865**	0.008	**-0.112**	0.892	**-2.784**	0.959	**-1.964**	0.892	-2.829	0.273	**-0.072**	0.982	**-0.556**
0.30	0.167	**-0.384**	0.807	-5.682	0.932	**-2.492**	0.969	**-1.458**	0.041	**-0.168**	0.915	-2.971	0.967	**-2.372**	0.920	-3.254	0.273	**-0.123**	0.979	**-1.058**
0.35	0.196	**-0.140**	0.812	-7.259	0.941	-3.602	0.968	**-2.512**	0.043	**-0.196**	0.926	-3.107	0.974	-3.772	0.930	-4.794	0.273	**-0.233**	0.982	**-1.737**
0.40	0.280	**-0.108**	0.816	-9.566	0.957	-2.918	0.974	**-2.533**	0.072	**-0.404**	0.890	-6.358	0.986	**-2.470**	0.943	-5.000	0.148	**-0.520**	0.980	**-2.784**
0.45	0.279	**-0.111**	0.808	-10.945	0.966	-3.095	0.990	**-1.084**	0.083	**-0.868**	0.888	-7.952	0.984	-3.234	0.951	-4.717	0.120	**-0.842**	0.973	-3.586
0.50	0.409	**-0.091**	0.803	-12.838	0.971	**-2.654**	0.993	**-0.805**	0.093	**-1.549**	0.890	-8.817	0.983	-3.284	0.960	-3.559	0.120	**-0.858**	0.973	-2.970
0.55	0.552	**-0.060**	0.787	-14.688	0.968	**-2.561**	0.997	**-0.346**	0.101	**-0.656**	0.879	-10.966	0.979	-3.784	0.963	**-2.821**	0.120	**-0.740**	0.980	**-1.872**
0.60	0.593	**-0.039**	0.759	-15.558	0.980	**-1.364**	0.985	**-1.315**	0.101	**-0.327**	0.880	-11.893	0.968	-5.229	0.967	**-2.364**	0.120	**-1.062**	0.987	**-1.040**
0.65	0.593	**-0.045**	0.740	-13.624	0.974	**-1.423**	0.998	**-0.154**	0.106	**-0.150**	0.877	-9.197	0.961	-5.083	0.924	-4.478	0.120	**-0.580**	0.990	**-0.642**
0.70	0.593	**-0.051**	0.738	-10.664	0.981	**-0.905**	0.992	**-0.401**	0.107	**-0.098**	0.867	-7.852	0.962	-3.671	0.904	-4.152	0.097	**-0.205**	0.938	-3.377
0.75	0.695	**-0.040**	0.718	-8.552	0.971	**-0.913**	0.979	**-0.876**	0.112	**-0.074**	0.860	-6.005	0.953	-3.305	0.878	-3.991	0.080	**-0.130**	0.916	-2.930
0.80	0.980	**-0.002**	0.686	-6.420	0.935	**-1.587**	0.960	**-0.920**	0.131	**-0.050**	0.873	-2.929	0.953	**-1.999**	0.851	-3.547	0.076	**-0.080**	0.899	**-2.725**
0.85	0.980	**-0.001**	0.619	-4.534	0.886	**-2.176**	0.927	**-1.219**	0.192	**-0.035**	0.838	**-2.180**	0.939	**-1.487**	0.817	**-1.469**	0.065	**-0.043**	0.894	**-1.077**
0.90	0.979	**0.000**	0.537	-3.660	0.868	**-1.440**	0.859	**-1.493**	0.213	**-0.023**	0.827	**-1.110**	0.924	**-1.008**	0.728	**-1.496**	0.060	**-0.028**	0.824	**-1.226**
0.95	2.173	**0.002**	0.636	**-1.511**	0.770	**-1.143**	0.795	**-0.922**	0.198	**-0.002**	0.687	**-1.118**	1.002	**0.013**	0.474	**-1.959**	0.071	**-0.003**	0.662	**-1.440**

Table 4: Johansen cointegration test results

Countries	Trace statistic H$_0$: rank = 0	Max. eigenvalue statistic H$_0$: rank = 0	Countries	Trace statistic H$_0$: rank = 0	Max. eigenvalue statistic H$_0$: rank = 0
Bahrain	27.728[a]	24.361[a]	Libya	28.950[a]	27.383[a]
Iran	26.221[b]	21.060[b]	Oman	31.607[a]	31.325[a]
Iraq	38.462[a]	35.213[a]	Qatar	36.454[a]	35.587[a]
Israel	13.896[b]	11.601[b]	Saudi Arabia	26.288[a]	21.202[a]
Kuwait	31.780[a]	29.343[a]	UAE	17.615[b]	14.269[b]

a is significant value at 1%, b is significant value at 5%

Table 5: Quantile Cointegration Stability Test Results

Model	Coeff.	$\text{Sup}_\tau \mid V_n(\tau) \mid$	CV1	CV5	CV10
Bahrain					
Model	**Coeff.**	**$\text{Sup}_\tau \mid V_n(\tau) \mid$**	**CV1**	**CV5**	**CV10**
TECH vs. ENV	β	**323.208**	357.016	224.510	157.471
	γ	**185.043**	99.508	58.757	40.061
Iran					
Model	**Coeff.**	**$\text{Sup}_\tau \mid V_n(\tau) \mid$**	**CV1**	**CV5**	**CV10**
TECH vs. ENV	β	**113.312**	199.755	117.833	94.461
	γ	**64.630**	142.744	66.873	50.008
Iraq					
Model	**Coeff.**	**$\text{Sup}_\tau \mid V_n(\tau) \mid$**	**CV1**	**CV5**	**CV10**
TECH vs. ENV	β	**50.895**	101.159	62.496	46.285
	γ	**75.133**	33.232	12.445	8.461
Israel					
Model	**Coeff.**	**$\text{Sup}_\tau \mid V_n(\tau) \mid$**	**CV1**	**CV5**	**CV10**
TECH vs. ENV	β	**67.498**	87.718	58.731	46.015
	γ	**118.881**	51.657	34.766	27.442
Kuwait					
Model	**Coeff.**	**$\text{Sup}_\tau \mid V_n(\tau) \mid$**	**CV1**	**CV5**	**CV10**
TECH vs. ENV	β	**110.017**	33.467	22.370	15.414
	γ	**164.268**	23.743	15.425	12.332
Libya					
Model	**Coeff.**	**$\text{Sup}_\tau \mid V_n(\tau) \mid$**	**CV1**	**CV5**	**CV10**
TECH vs. ENV	β	**122.607**	96.095	50.897	38.119
	γ	**19.798**	29.662	13.729	8.079
Oman					
Model	**Coeff.**	**$\text{Sup}_\tau \mid V_n(\tau) \mid$**	**CV1**	**CV5**	**CV10**
TECH vs. ENV	β	**99.359**	135.919	90.189	67.206
	γ	**58.514**	45.463	23.719	16.568
Qatar					
Model	**Coeff.**	**$\text{Sup}_\tau \mid V_n(\tau) \mid$**	**CV1**	**CV5**	**CV10**
TECH vs. ENV	β	**193.908**	154.679	94.929	76.676
	γ	**43.198**	54.842	32.247	20.999
Saudi Arabia					
Model	**Coeff.**	**$\text{Sup}_\tau \mid V_n(\tau) \mid$**	**CV1**	**CV5**	**CV10**
TECH vs. ENV	β	**280.618**	161.029	76.7744	57.029
	γ	**143.789**	88.717	41.897	32.011
UAE					
Model	**Coeff.**	**$\text{Sup}_\tau \mid V_n(\tau) \mid$**	**CV1**	**CV5**	**CV10**
TECH vs. ENV	β	**382.328**	184.475	92.501	66.271
	γ	**117.332**	80.110	38.681	23.094

Note: This table presents the results of the quantile cointegration test of Xiao (2009). We test the stability of the coefficients β and γ in the quantile cointegration model. CV1, CV5, and CV10 are the critical values of statistical significance at 1%, 5%, and 10%, respectively. We use 1000 Monte Carlo simulations to generate the critical values. We use an equally spaced grid of 19 quantiles, [0.05-0.95].

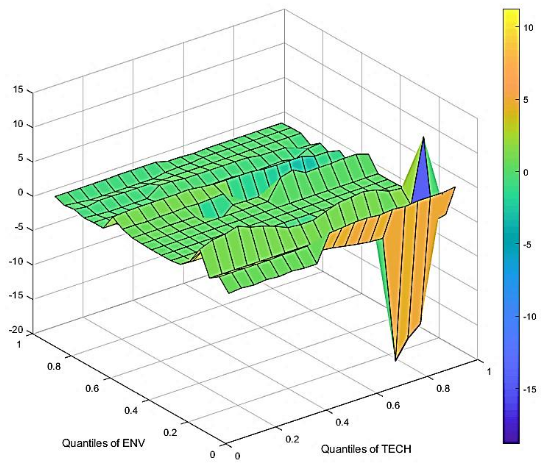
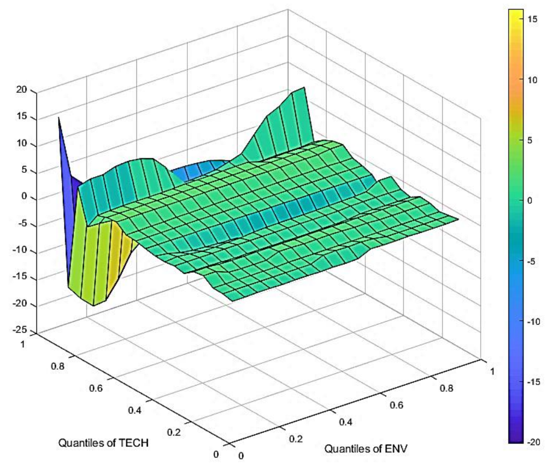
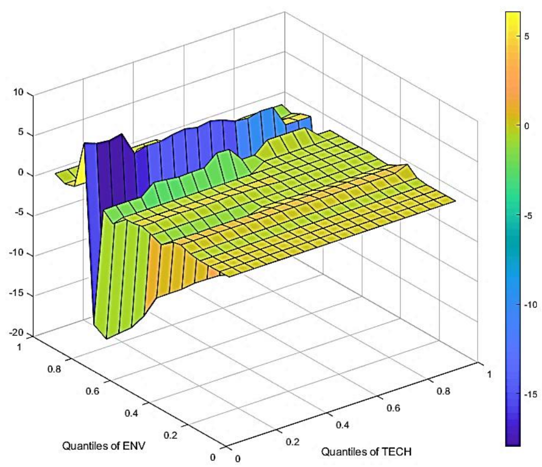
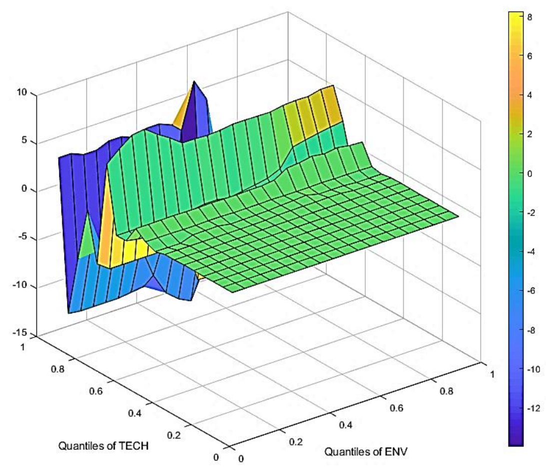
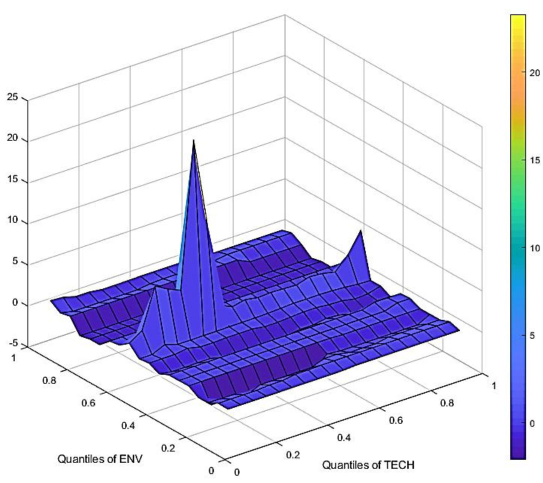
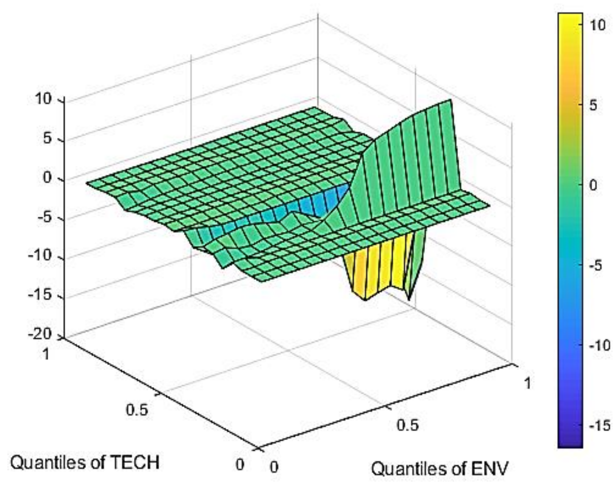
Table 6: Results of Granger Causality Test in Quantiles

Bahrain																					
	Lags	**0.05**	**0.10**	**0.15**	**0.20**	**0.25**	**0.30**	**0.35**	**0.40**	**0.45**	**0.50**	**0.55**	**0.60**	**0.65**	**0.70**	**0.75**	**0.80**	**0.85**	**0.90**	**0.95**	**Total**
TECH to ENV	1	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.813	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
	2	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.820	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
	3	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.735	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
ENV to TECH	1	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.208	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
	2	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.226	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
	3	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.251	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
Iran																					
	Lags	**0.05**	**0.10**	**0.15**	**0.20**	**0.25**	**0.30**	**0.35**	**0.40**	**0.45**	**0.50**	**0.55**	**0.60**	**0.65**	**0.70**	**0.75**	**0.80**	**0.85**	**0.90**	**0.95**	**Total**
TECH to ENV	1	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.753	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
	2	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.703	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
	3	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.053	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
ENV to TECH	1	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.806	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
	2	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.749	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
	3	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.707	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
Iraq																					
	Lags	**0.05**	**0.10**	**0.15**	**0.20**	**0.250**	**0.30**	**0.35**	**0.40**	**0.45**	**0.50**	**0.55**	**0.60**	**0.65**	**0.70**	**0.75**	**0.80**	**0.85**	**0.90**	**0.95**	**Total**
TECH to ENV	1	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
	2	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
	3	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
ENV to TECH	1	0.007	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.032	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
	2	0.007	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.007	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
	3	0.007	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.018	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
Israel																					
	Lags	**0.05**	**0.10**	**0.15**	**0.20**	**0.25**	**0.30**	**0.35**	**0.40**	**0.45**	**0.50**	**0.55**	**0.60**	**0.65**	**0.70**	**0.75**	**0.80**	**0.85**	**0.90**	**0.95**	**Total**
TECH to ENV	1	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.021	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
	2	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.021	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
	3	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.021	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
ENV to TECH	1	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.336	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
	2	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.346	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
	3	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.399	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
Kuwait																					
	Lags	**0.05**	**0.10**	**0.15**	**0.20**	**0.25**	**0.30**	**0.35**	**0.40**	**0.45**	**0.50**	**0.55**	**0.60**	**0.65**	**0.70**	**0.75**	**0.80**	**0.85**	**0.90**	**0.95**	**Total**
TECH to ENV	1	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.693	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
	2	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.700	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
	3	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.820	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
ENV to TECH	1	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.866	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
	2	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.746	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
	3	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.707	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
Libya																					

	Lags	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.55	0.60	0.65	0.70	0.75	0.80	0.85	0.90	0.95	Total
TECH to ENV	1	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.689	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
	2	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.675	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
	3	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.664	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
ENV to TECH	1	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
	2	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
	3	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
Oman																					
	Lags	**0.05**	**0.10**	**0.15**	**0.20**	**0.25**	**0.30**	**0.35**	**0.40**	**0.45**	**0.50**	**0.55**	**0.60**	**0.65**	**0.70**	**0.75**	**0.80**	**0.85**	**0.90**	**0.95**	**Total**
TECH to ENV	1	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.049	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
	2	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.035	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
	3	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.018	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
ENV to TECH	1	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
	2	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
	3	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
Qatar																					
	Lags	**0.05**	**0.10**	**0.15**	**0.20**	**0.25**	**0.30**	**0.35**	**0.40**	**0.45**	**0.50**	**0.55**	**0.60**	**0.65**	**0.70**	**0.75**	**0.80**	**0.85**	**0.90**	**0.95**	**Total**
TECH to ENV	1	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.223	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
	2	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.180	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
	3	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.180	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
ENV to TECH	1	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
	2	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
	3	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
Saudi Arabia																					
	Lags	**0.05**	**0.10**	**0.15**	**0.20**	**0.25**	**0.30**	**0.35**	**0.40**	**0.45**	**0.50**	**0.55**	**0.60**	**0.65**	**0.70**	**0.75**	**0.80**	**0.85**	**0.90**	**0.95**	**Total**
TECH to ENV	1	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.922	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
	2	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.915	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
	3	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.954	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
ENV to TECH	1	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
	2	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
	3	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
UAE																					
	Lags	**0.05**	**0.10**	**0.15**	**0.20**	**0.25**	**0.30**	**0.35**	**0.40**	**0.45**	**0.50**	**0.55**	**0.60**	**0.65**	**0.70**	**0.75**	**0.80**	**0.85**	**0.90**	**0.95**	**Total**
TECH to ENV	1	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.286	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
	2	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.346	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
	3	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.502	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
ENV to TECH	1	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
	2	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
	3	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004

Note: The subsample size is t = 51 for a sample of T = 336 observations.

Figure 1: Quantile-on-Quantile (QQ) estimates of the slope coefficient

Impact of Technological Progression (TECH) on Environmental Quality (ENV)	Impact of Environmental Quality (ENV) on Technological Progression (TECH)
1. Bahrain 	
2. Iran 	
3. Iraq 	

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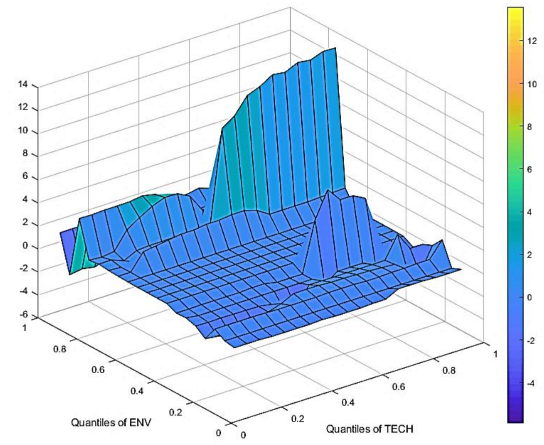
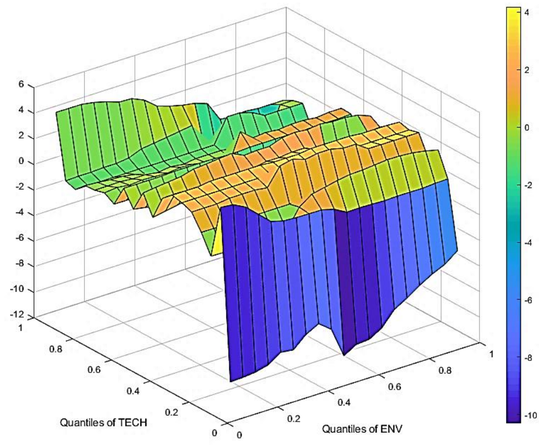
</td><td></td></tr>
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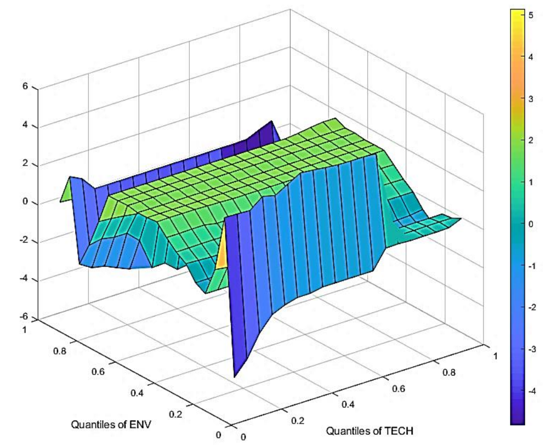
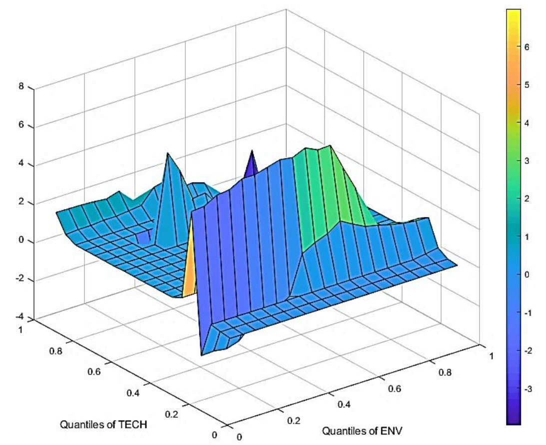
</td><td></td></tr>
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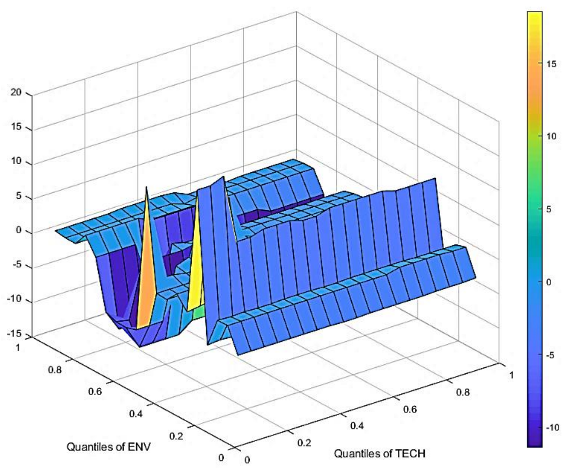
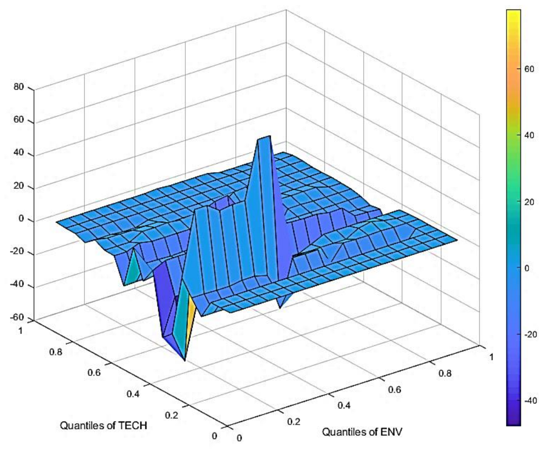
</td><td></td></tr>
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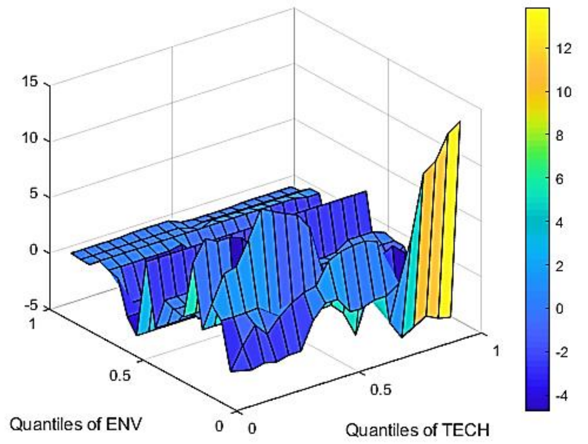
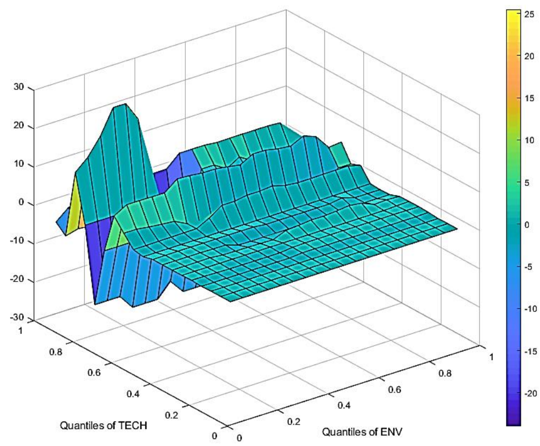
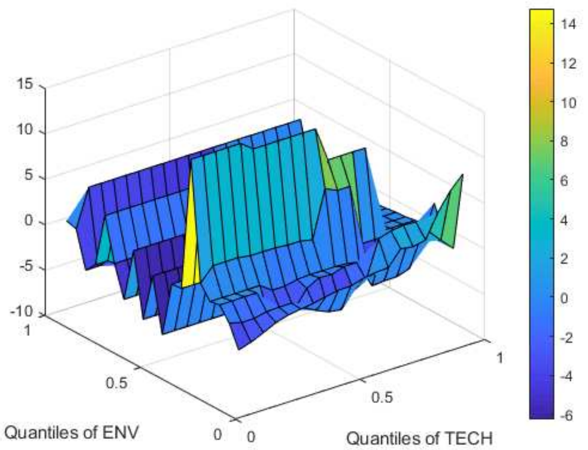
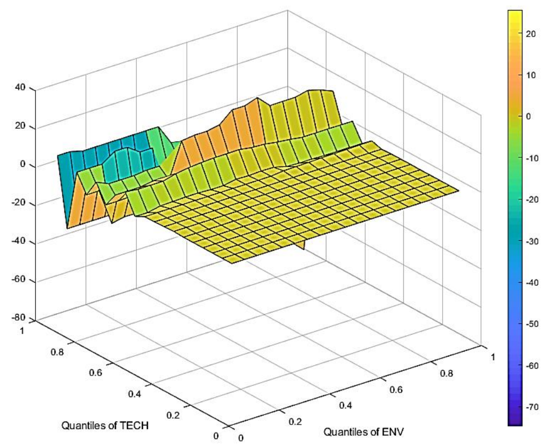


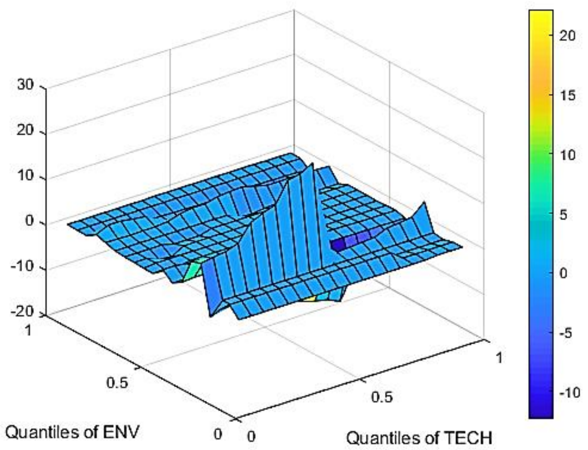


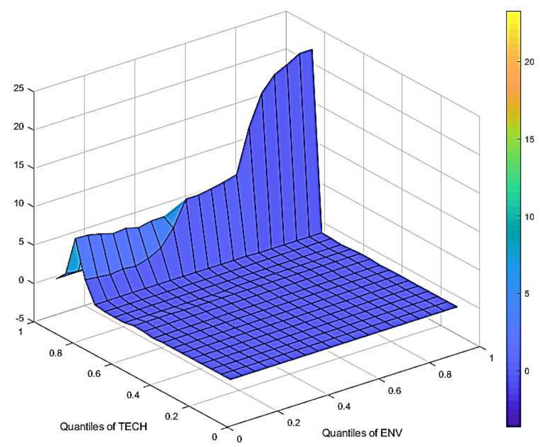
8. Qatar



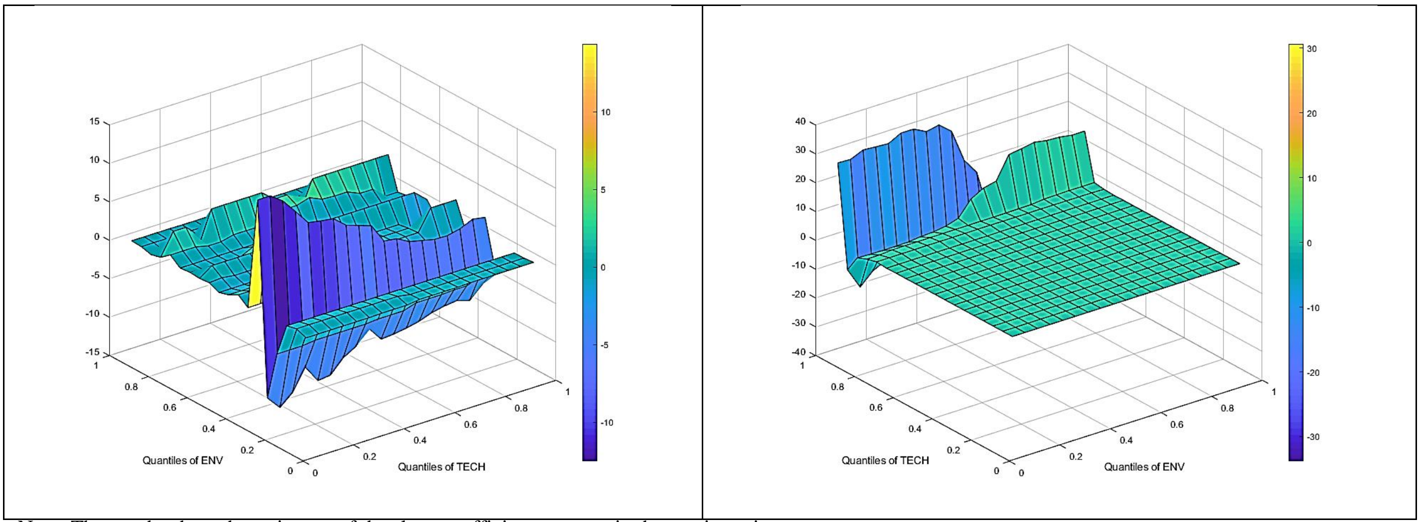


9. Saudi Arabia



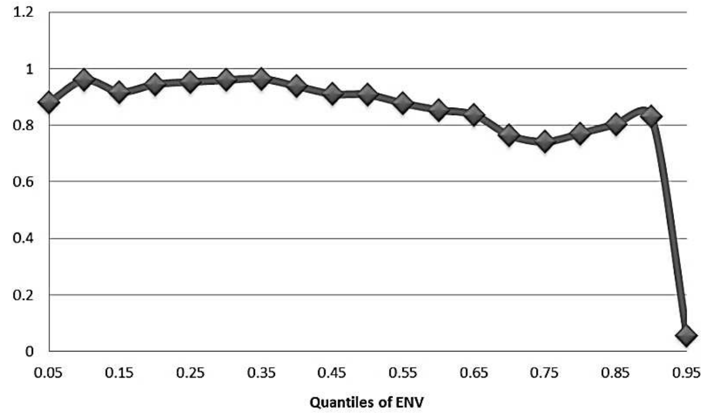
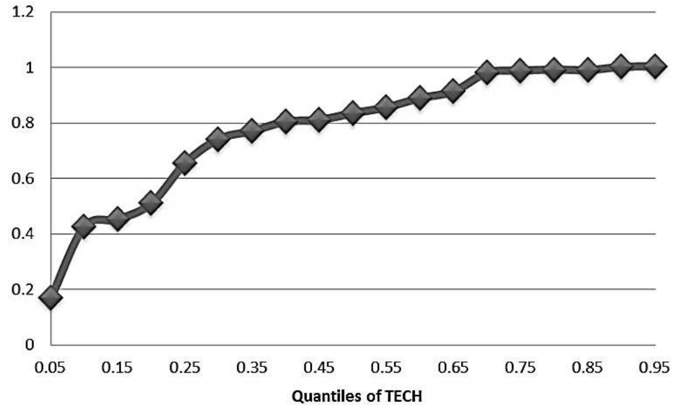
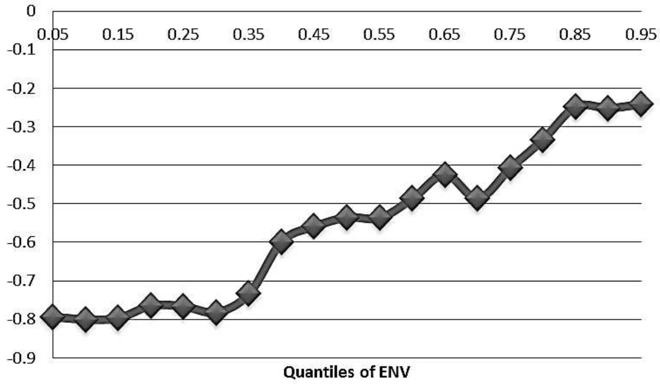
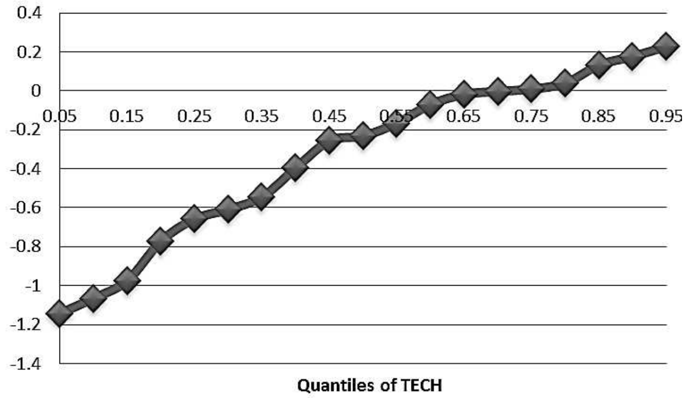
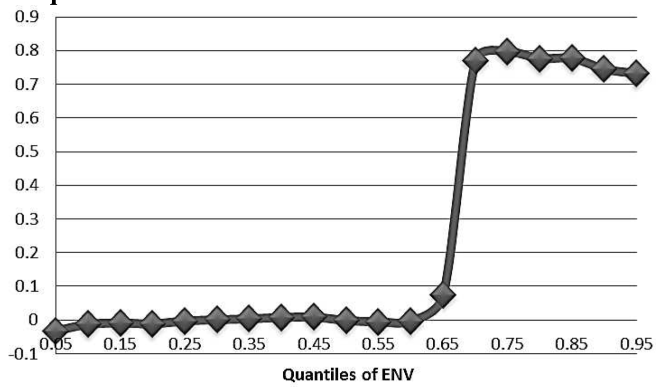
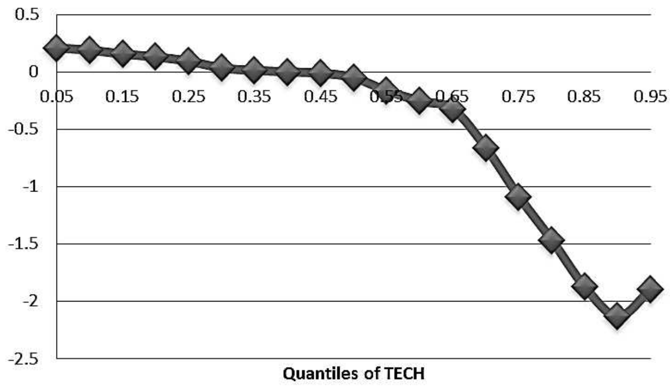
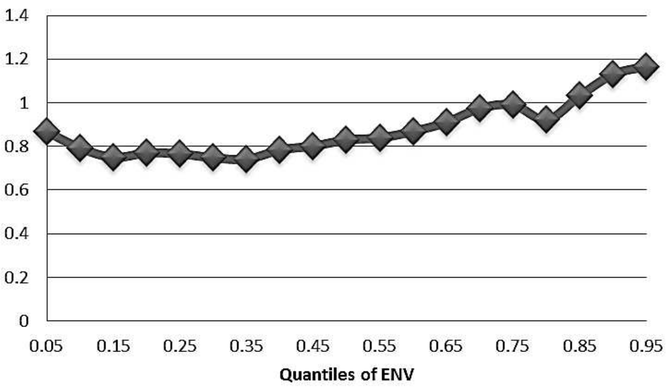
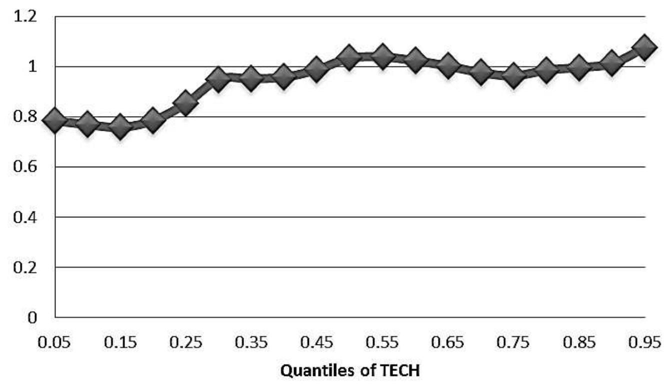


10. UAE

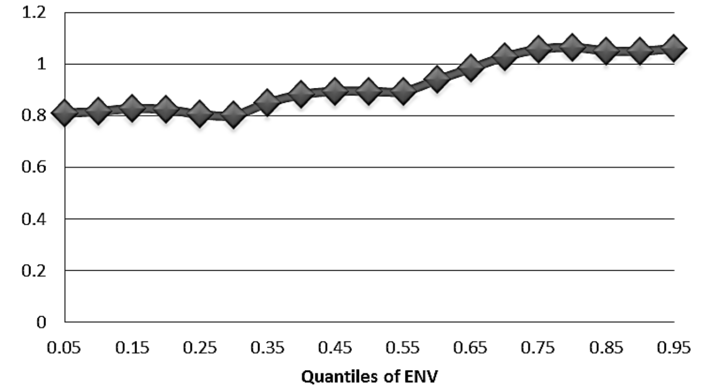


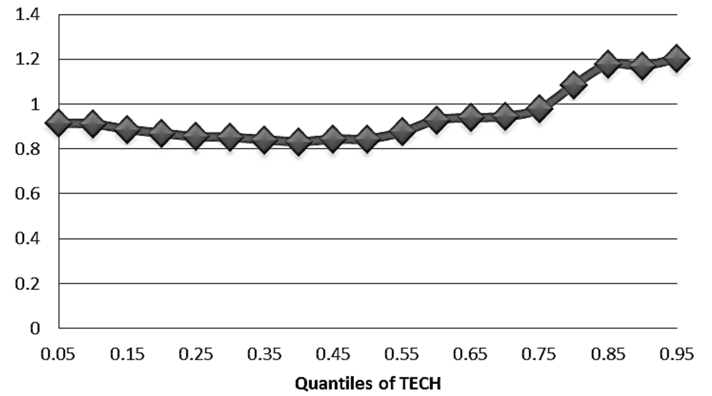
Note: The graphs show the estimates of the slope coefficient $\beta_1(\theta, \tau)$ in the *z*-axis against

Figure 2: Quantile regression estimates of the slope coefficient

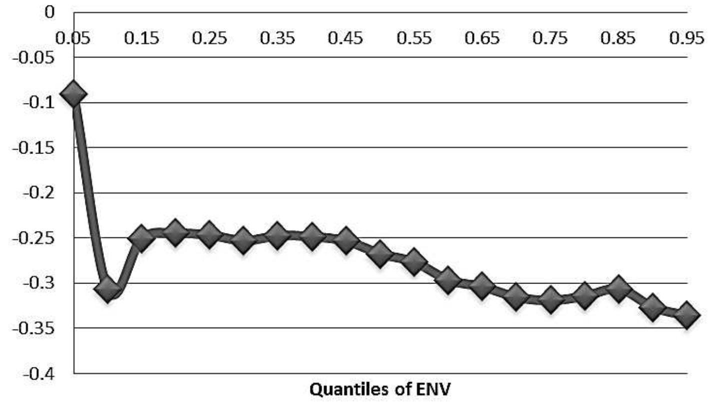
Impact of Technological Progression (TECH) on Environmental Quality (ENV)	Impact of Environmental Quality (ENV) on Technological Progression (TECH)
1. Bahrain 	
2. Iran 	
3. Iraq 	
4. Israel 	

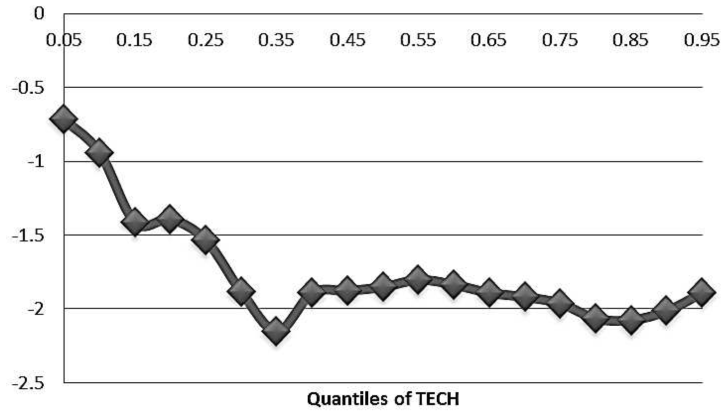
5. Kuwait



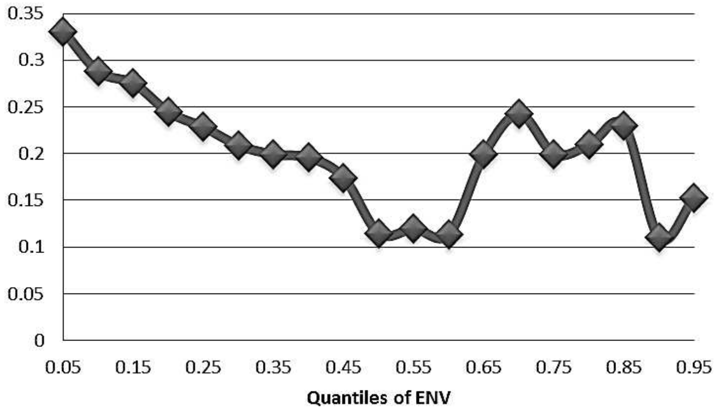


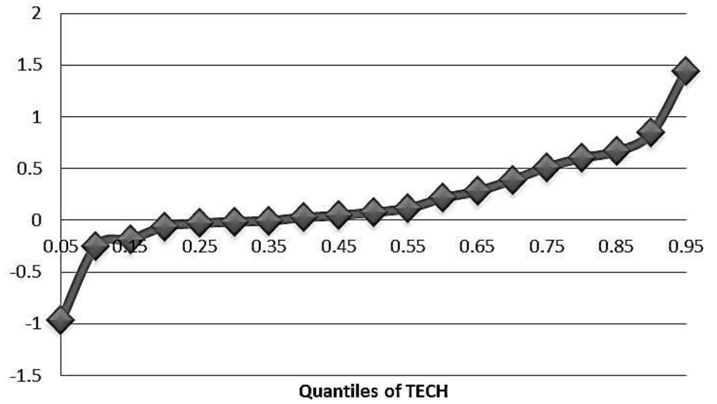
6. Libya



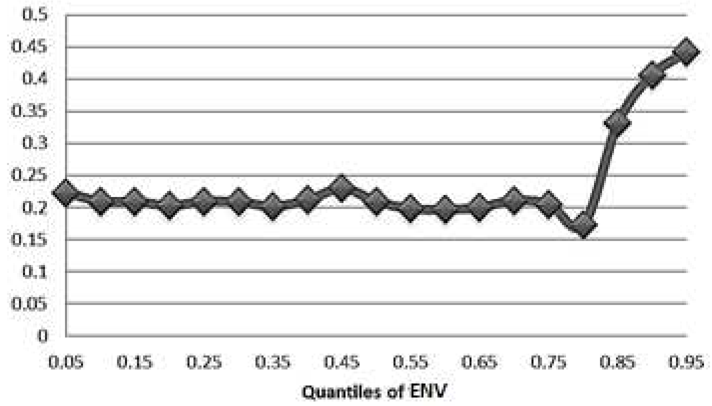


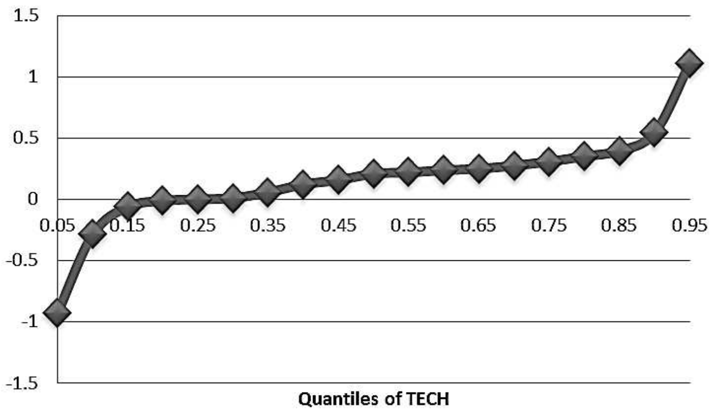
7. Oman



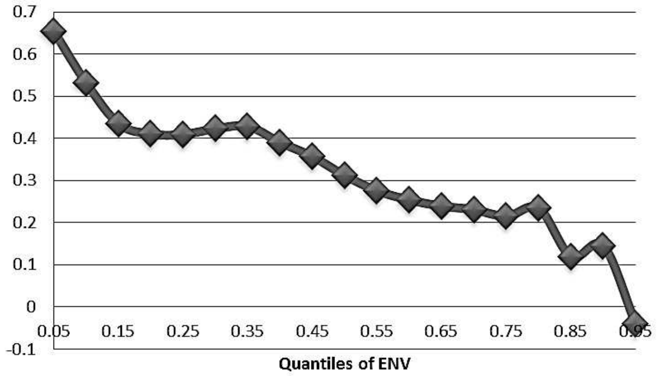


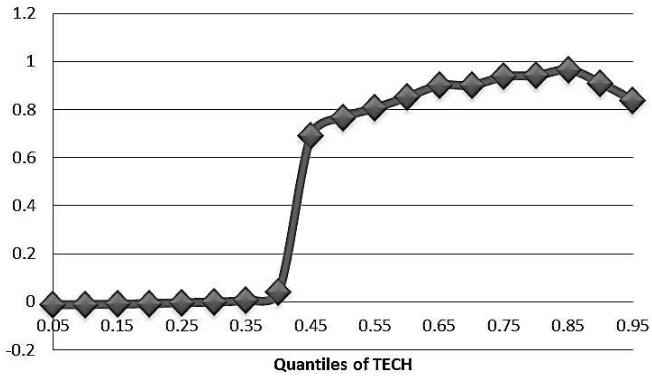
8. Qatar



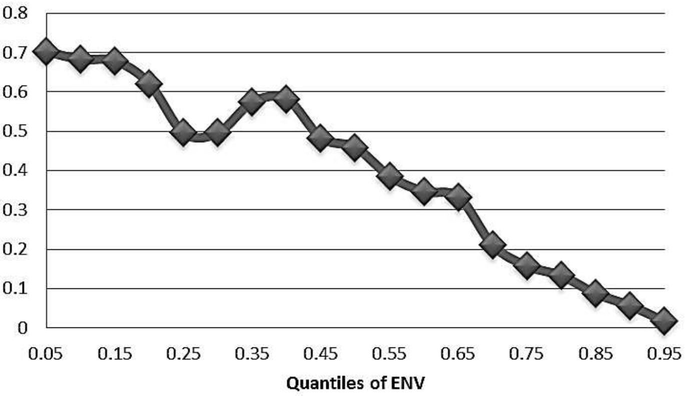


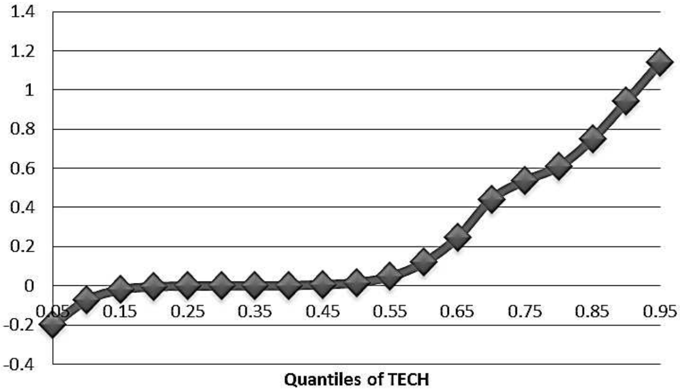
9. Saudi Arabia





10. UAE





Note: The graphs exhibit the slope estimates of the standard quantile regression.