Does Distribution of Energy Innovation impact Distribution of Income: A Quantile-based SDG Modeling Approach

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Abstract

Despite the ongoing research on energy innovation and economic growth, little is known on how degree of energy innovation impacts income inequality within a nation. To address this research gap, we have developed a bivariate model to analyze how distribution of energy innovation affects the income distribution in a certain country. Using the Fisher Ideal Index, we have calculated energy efficiency as an indicator of energy innovation. Quantile-on-Quantile regression has been applied to capture the impact on energy innovation across different income quantiles in Next 11 (N11) countries. Results show that energy innovation can have different outcomes, across the member countries of N11 group, namely a) equitable and positive impact, (b) negative impact, and (c) inequitable impact in terms of distribution of income. We have inferred important policy implications, which might lead to sustainable development strategies in N11 countries. This study is one of the first to establish the direct link between energy innovation and income inequality across different quantiles within a nation. Further, we successfully demonstrate the application of advanced quantile methods in inferring Sustainable Development Goal (SDG) focused policy implications.

Keywords: Energy Innovation; Energy Efficiency; Income Inequality; Sustainable Development Goals; Quantile-on-Quantile Regression

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1. Introduction

In the last century, we observed that economic growth and energy demand are highly correlated. Endeavors of economies towards rapid development eventually increased energy demand, while constraining of energy supply might dampen the GDP growth rate. This has been a general observation since the initiation of the Industrial Revolution. However, with rising priorities towards growth, economies have pushed towards increased use of fossil fuels, which further accelerated the demand for energy. A recent study by Mckinsey encompassing 30 sectors in 146 countries suggests that economic growth and energy demand has started to decouple across all countries (Mckinsey Quarterly, 2019). One of the main reasons for the commencement of such decoupling effect is the rising importance of energy efficiency. Findings of the report suggests that this increase in energy efficiency is characterized or resulted due to investment in technological innovation in the form of green technology in the energy sector. Such drivers assumed importance in the last decade due to the commitment of nations towards 2030 Agenda for Sustainable Development. The agenda formulated the Sustainable Development Goals (SDGs), adopted by all member states of the United Nations, with the objective of tackling social, economic, and environmental concerns together hand-in-hand. In light of this framework, researchers also highlighted the need to adopt a multi-pronged policy approach, while dealing with issues pertaining to attaining SDG goals (Sinha et al., 2020a, b; Le Blanc, 2015). In this view, tackling climate change (SDG 13) might require nations to invest in clean technologies that are affordable to the consumers (SDG 7), for which nations will eventually have to focus on innovation and corresponding infrastructure development (SDG 9). However, the question somewhat remain unanswered as to how such initiatives might have an impact on the economic growth of a nation. In other words, the degree of energy innovation prevailing in nations might have an impact on the distribution of income. This assumes great importance to the emerging markets, where the priority towards economic growth is high, but at the same time one needs to invest in energy innovation to tackle climate change.

On one hand, when increasing the level of income is the major priority in emerging economies, prevailing skewed economic growth pattern in these nations is more prone towards enhancing income inequalities. Often such emerging nations are burdened with this disparity of income distribution, where a large portion of the income is usually concentrated to a small percentage of the nation's population. Since income inequality has direct impact on macroeconomic factors such as economic growth (Kennedy et al., 2017; Kim, 2016), health (Rözer and Volker, 2016; Kawachi and Kennedy, 1999) and poverty (Farzanegan and Habibpour, 2017; Kakwani, 1980), nations strive to bring in measures, which might reduce this gap (SDG 10). It is estimated that, by 2030 the middle class is predicted to grow by 150% in the BRIC nations and by 116% in Next 11 countries. As a result, income inequality is expected to be one of the most important factors to be kept in mind while recommending any policy in line with the 2030 SDG targets. We therefore, motivate our study with the attempt to understand whether emerging markets are successful in promoting energy innovation, while keeping in mind the need to reduce inequalities, with the objective of alleviating environmental degradation. Hence, we consider a bivariate model for our study with a single dimension focus on how the degree of energy innovation impacts different income level groups within a nation. This motivation of the study can be considered an extension of *Schumpeter's Innovation Theory of Profit*, which implicitly suggests the accumulation of wealth in the hands of few by means of innovation (Schumpeter, 1934). Though this theory was developed in keeping with the entrepreneurial uprising in the Western nations, this theory can be reciprocated within the boundaries of energy innovation, as like any forms of innovation, energy innovation might be considered as a driver of sustainable development in the emerging economies, and therefore, the theoretical framework of the study can be considered as an extension of this theory.

We purposefully choose Next 11 economies[2] (thereafter N11) as the unit of analysis for specific reasons. First, these countries are one of the important emerging markets that have the potential of becoming world's largest economies. Hence, they not only pose a threat to the existing leading economies, but also create a strong basis for discussion concerning economic growth and climate change. Being characterized as the emerging economies, it is evident that the policymakers in these nations are more interested in attaining economic growth, rather than protecting environmental quality (O'Neill, 2018). Second, due to their primary focus on economic activities, these countries have become less energy efficient, and consequently are becoming prone to environmental concerns in near future. This concern is further substantiated by the fact that N11 and BRICS contribute more towards carbon emissions than any other developing or developed countries in the world (World Bank, 2019). The N11 nations are characterized by the incidents of energy poverty issues, which can have serious consequences on the production processes, and the subsequent economic growth. The dependence of these nations on the fossil fuel-based solutions and rising demand for energy are responsible for this mounting issue of un-served demand of energy, and prevalence of this issue gives a proper background for these nations to make progressions towards energy innovation. Third, N11 countries have mixed exposure towards degree of investments in technological innovation (Sinha et al., 2020a). For instance, South Korea and Turkey have better technological footprint and have rivaled BRICS counterparts, such as Russia and Brazil, while other members of N11 have focused more on growth and infrastructure development. Now, in continuation with the discussion on

[2] Bangladesh, Egypt, Indonesia, Iran, South Korea, Mexico, Nigeria, Pakistan, Philippines, Turkey, and Vietnam.

infrastructural development, it needs to be remembered that the economic growth pattern prevailing in these nations has resulted in the issue of energy poverty, which is a major reason behind the rising disparity in income in these nations. Therefore, it can be assumed that the innovations in the pursuit of improving energy efficiency might have brought forth the waves of sustainable development in these nations. Energy being a major driver of economic growth, energy innovation might be considered a driver of sustainable development in these nations, and hence, the energy façade of the innovation can be seemingly more relevant to these nations. As a result, understanding the impact of varying degree of energy innovation is important in case of N11 economies and its consequence towards income inequality, because the policy-level myopia might restrict the policymakers to invest in energy innovation by forgoing short-run economic benefits over a long term.

Very few studies to the best of our knowledge have attempted to address the relationship between energy innovation and income distribution in emerging and frontier markets from a policymaking perspective. Khattak et al. (2020) investigated the interaction between innovation, renewable energy consumption and income on carbon emissions for BRICS nations. Further, a technical report by Drehobl and Ross (2016) addressed the energy burdens in cities across the United States, while making an attempt to address the role of energy innovation towards improving low income and marginalized communities in the United States. None of the studies addressed a focused issue on the impact of energy innovation on income distribution in frontier markets, and therefore, a void in policy formulation for ascertaining sustainable development exists. This paper attempts to address this gap by analyzing the impact of energy innovation on disparity in income in emerging and frontier markets. Our study is critical as it attempts to explore whether the degree of energy innovation is instrumental in bringing a homogenous change in income generation across such markets, with a special focus on N11 countries. This assumes importance as priorities towards clean energy generation and achieving economic growth are often at crossroads in such economies. The policy-level contribution of this study emerges from a multi-pronged SDG framework that we intend to design by analyzing the association between degree of energy innovation and the inequality in income levels across N11 economies. In this framework, the energy affordability (SDG 7), infrastructural development (SDG 9) and climate action (SDG 13) will be focused at the primary level of policy design, whereas attainment of economic growth (SDG 8) and diminishment in income inequality (SDG 10) will be focused at secondary and tertiary stages. This policy level contribution of the study calls for a suitable methodological design, which will be able to account for the distribution of the entire data spectrum. Moreover, it also needs to be remembered that the impact of the control policy parameters needs to be assessed across the spectrum of the target policy parameter. Owing to this reason, we apply Quantile-on-Quantile regression (Sim and Zhou, 2015) on a bivariate model involving distribution of energy innovation and income distribution. One of the most important advantages of using the advanced quantile methods is the ability to evaluate the impact of the entire quantile distribution of one variable on the quantile distribution of the other variable. This helps us to capture the degree of energy innovation and the level of income inequality across the spectrum of the data, and thereby, allowing to depict a wholesome picture regarding the impact. The other advantage is that it helps policymakers target policy enforcement decisions at various levels across the quantiles (Sharif et al., 2020). These advantages of this methodological adaptation comply with the policy contribution of the study, and there lies the analytical contribution of the study.

The remainder of the paper is as follows: Section 2 details the literature review on innovation, sustainable development Goals and income distribution in various contexts. Section 3 explains the methodology adopted for our study. Section 4 presents the results of the study and analyses the results in line with the research objectives for each country within N11. Section 5 concludes the paper by highlighting the policy implications of this study.

2. Literature review

With the support of technological progression, economy strives to progress. This technological progression brings about innovations, which help the economy to grow. While attaining this growth trajectory, it might be possible that the diffusion of innovation is not equitable across the nation, and therefore, the wealth generated in the course of economic growth is accumulated in the hands of few. This phenomenon is reflected in the income inequality of the nation, and this issue can be attributed to the lack of proper distribution of innovation, in terms of technological or knowledge diffusion. In keeping with the objective of our study, we will review the studies on this particular aspect.

The effect of innovation on inequality has been the focus in the recent literature. Few of the studies find that the increase in the level of innovation increases the income inequality level. Cozzi and Impullitti (2010) develop a model to show that increase in government spending in the US, lead to an increase in the wage inequality. Lee (2011) found that increase in innovation leads to an increase in the wage inequality across European countries during 1996-2001. Lee and Rodríguez-Pose (2013) estimate the effect of innovation on income inequality across 13 countries of Europe and whole of USA over the period 1996-2001 and 1996-2009. They find that while innovation is negatively and strongly associated with the income inequality across all the countries in Europe, there is no stable link in USA and attribute it to the limited labor markets mobility in Europe as compared to in USA. Aghion et al. (2019) reinforce the above findings that increase in innovation raises the income of the high-income group and the level of inequality overall over the period 1975-2010 in USA. Breau et al. (2014) explain the positive relationship between innovation and wage inequality in a set of Canadian cities over 1996-2006, using the skill-biased technology theory. Hémous and Olsen (2014) contribute by developing a model to explain this phenomenon. The model consists of three stages: initially the low-skill wages and automation are low; then wage premium for low skill workers increases due to horizontal innovation and leads to automation and reduction in growth in wage premium of low-skill wages. This is followed by the stabilization of the share of automated products leading to lower growth in low-skill wages and consequently lead to greater inequality.

On the other hand, there is a strand of studies those conclude that an increase in innovation leads to a reduction in the income inequality. Antonelli and Gehringer (2017) estimate the effect of technological change on the income distribution for a set of advanced economies using quantile regression. They find that increase in the level of innovation reduces the income inequality through the effect of creative destruction. Similarly, Claudia et al. (2018) study the effect of innovation on income inequality on a larger scale, for 126 European Union spatial units and find that although increase in level of innovation increases the income of high-income groups, it reduces the overall inequality by raising the income of other income-groups as well. Włodarczyk (2017) find that the higher number of patents and higher values on Creative Economy Index leads to a decrease in the income inequality across 30 European countries. In a recent study, Tchamyou et al. (2019) find that increase or innovation in technology reduces the income inequality across 46 states of Africa over the period 1996-2014.

The above literature review suggests that the effect of innovation on income inequality is contradictory and inconclusive. This effect is important from the perspective of the SDGs, as concentrating on science, technology and innovation might be the path to socio-environmentally sustainable society (Walsh et al., 2020). Now, when economic growth pattern of the emerging economies are considered, the energy aspect of innovation becomes more prevalent, as the effect of energy innovation on income inequality is question of greater importance, since it addresses objectives of two SDGs: (i) Objective of SDG 7 (affordable and clean energy) and (ii) Objective of SDG 10 (reduced inequalities). By far, in the literature of energy economics, we have not encountered any study that analyzes this aspect, and our study addresses this research gap. From the perspective of sustainable development, this association might be important for achieving the objectives of SDGs, and this study aims at devising suitable policy framework for the N11 member countries, thereby contributing to the literature from the policymaking perspective.

3. Methodological framework and data

3.1. Parameterizing energy innovation

In this study, we intend to analyze the impact of distribution of Energy Innovation of Income distribution. In this pursuit, we need to determine an indicator for measuring energy innovation. For energy innovation, indictor can be designed either from the input or output perspective. If the input side perspective is considered, then the possible indicators can be (a) number of patent, copyright, and trademark applications, (b) public expenditure on research and development, (c) number of researchers present in a country, and others (Sinha et al., 2020a, b). However, it is hard to determine the level of realization of these indicators, as the research endeavors taken up by virtue of these indicators might not prove to be fruitful in ascertaining the realization of innovations. Hence, output perspective might be more symbolic in terms of indicating the energy innovations, and in this study, we have adopted the output oriented perspective for representing energy innovations. The indicator chosen by us is the energy efficiency, as it can indicate the impact of energy innovations (Kern, 2012; Yun and Lee, 2015). This energy efficiency is calculated through Fisher Ideal Index (Fisher, 1921), as this index is created by combination of structural movement and energy intensity (Metcalf, 2008). Leal and Marques (2019) have already paved the way to compute energy efficiency using the Fisher Ideal index. It is calculated in the following steps:

Step 1: If we assume the energy intensity of a sector is EIS_{it}, and structural transformation in economy is STE_{it}, then the cumulative energy intensity EI_t will take the following form:

$$EI_t = TE_t/OP_t = \sum_i (TE_{it}/OP_{it})(OP_{it}/OP_t) = \sum_i EIS_{it}STE_{it} \quad (1)$$

Here, TE_t and OP_t are total energy consumption and total economic output at time t, respectively. TE_{it} and OP_{it} are energy consumption and economic output at time t for sector i.

Step 2: Once the cumulative energy intensity EI_t is calculated, energy intensity index EII_t is calculated by taking a ratio of cumulative energy intensity at time t with respect to the base year ($t = 0$). Assuming the latter value to be EI_0, the EII_t is given by:

$$EII_t = EI_t/EI_0 = \sum_i EIS_{it}STE_{it} / \sum_i EIS_{i0}STE_{i0} \quad (2)$$

Step 3: In order to arrive at the Fisher Ideal Index, Laspeyres (*LI*) and Paasche (*PI*) indices need to be calculated:

$$LI_t = \sum_i EIS_{it}STE_{i0} / \sum_i EIS_{i0}STE_{i0} \quad (3)$$

$$PI_t = \sum_i EIS_{it}STE_{i0} / \sum_i EIS_{i0}STE_{it} \quad (4)$$

Step 4: Fisher Ideal Index (*FI*) is the geometric weighted average of Laspeyres (*LI*) and Paasche (*PI*) indices, and it takes the following functional form:

$$FI_t = \sqrt{LI_t * PI_t} \quad (5)$$

The output of Eq. (5) can be denoted as the energy efficiency calculated through Fisher Ideal Index. If FI_t is calculated at time t_1 and t_2, and if $FI|_{t=t1} > FI|_{t=t2}$, then it indicates more energy consumed by the sector, and thereby denoting drop in energy efficiency.

3.2. Quantile-on-quantile regression approach

Following the estimation of energy efficiency by Fisher Ideal Index, this study utilizes Quantile on Quantile Regression (QQR) approach concocted by Sim and Zhou (2015). This methodology is a fusion of ordinary least square (OLS) and quantile regression. Typical quantile regression approach divulges the effects of explanatory model parameter on the different quantiles of the dependent model parameter. Additionally, standard OLS weighs the impact of a precise quantile of explanatory model parameter on the dependent model parameter. QQR method fuses both these methods to explore the connotation between quantiles of these parameters. QQR model deliberated based on the model parameters of this study is as per the following:

$$INC_t = \sigma^q(FI_t) + \epsilon_t^q \quad (6)$$

Here, q characterizes the q^{th} quantile of the restricted band of the principle model parameter, and ϵ_t^q expounds the regression residual with intermittent q^{th} quantile predicted to be null. $\sigma^q(.)$ is an unspecified function, as no forgoing information on the parametric implication can be attained.

3.3. Data

In this study, the impact of energy innovation distribution on income distribution has been analyzed for the N11 countries over 1990-2016. The annual data on per capita gross domestic product (current USD) and gross capital formation (current USD) have been collected from the World Development Indicators (World Bank, 2019), the data of gross value added by kind of economic activity have been collected from United Nations Statistics Division (UNSD, 2019), the data on final energy consumption by sector have been collected from International Energy

Agency (IEA, 2019). The data have been transformed from annual to quarterly frequency by using quadratic-match-sum technique (Lahiani et al., 2017; Sharif et al., 2020a, b). As the reliable data on income distribution was not available, the quantile distribution of per capita income has been considered as distribution of income (see Mallick et al., 2019). Before starting off with the analysis, quantile unit root tests and quantile cointegration tests are conducted on the model parameters. The test outcomes recorded in Appendix 1 and 2 suggest that the model parameters are integrated to unit order and they are also cointegrated for the long run.

4. Results and analysis

4.1. Quantile-Quantile plot analysis

Before proceeding with the analysis, Quantile-Quantile (QQ) plot might give us an idea about the quantile distribution, so that a glimpse of the intended impact can be obtained. In this pursuit, QQ plots for Energy Innovation and Income across the N11 member nations have been prepared and they are reported in Figure 1. All of the plots for the individual countries will be discussed subsequently.

<Place for Figure 1>

For **Bangladesh**, the income is skewed towards the lower quantiles, while the energy innovation has a tendency towards the middle and higher quantiles. Therefore, it can be inferred that the distributive pattern of energy innovation is responsible for skewed income distribution, while not favoring the citizens from lower strata of income. In case of **Egypt** and **Indonesia**, both the income and energy innovation are bullish towards the lower quantiles. This pattern divulges that the distribution of energy innovation is pro-poor and might not be favorable to the people from the upper strata of income. In case of **Iran**, income is distributed majorly towards lower and middle quantiles, whereas energy innovation is found to be having a central tendency.

In this case, the energy innovation might have a stronger impact on the people from the middle income category, followed by lower and upper quantiles, respectively. In case of **South Korea**, income is distributed across all the quantiles, while energy innovation is demonstrating bulling tendency in the middle and upper quantiles. This particular pattern divulges the probability of higher impact of energy innovation on impact at its higher quantiles, while depriving the people from lower strata of income. For **Mexico**, income distribution is bullish towards the middle and upper quantiles, whereas energy innovation is bullish towards lower and middle quantiles. It can be inferred from this pattern that the middle class people might obtain the benefits of energy innovations, while the poor and rich citizens will be affected in nearly similar manner. The case of **Nigeria** is nearly similar to that of Bangladesh, as the bullish nature of income and energy innovation can only be seen at the lower quantiles, and hence, the impact of energy innovation might be more favorable towards the people from higher strata of income. **Pakistan** is showing bullish pattern in the lower and upper quantiles of income, and nearly similar pattern is visible in case of energy innovation, as well. So, it can be assumed that the impact of energy innovation on income might be equitable across the quantiles. Nearly similar to Bangladesh and Nigeria, the case of **Philippines** demonstrates bullish nature of income and energy innovation can only be seen at the lower and middle quantiles, respectively. Hence, it can be inferred that the impact of energy innovation will be more towards the people from upper quantile of income. The case of **Turkey** is nearly similar that of South Korea, as the income distribution is fairly across all quantiles, except the top and bottom most quantiles. The energy innovation is also demonstrating a central tendency. It shows that the impact of energy innovation might be equitable across all quantiles of income. Like Turkey, **Vietnam** demonstrates an equitable distribution of income, while the energy innovation is highly skewed towards the lower quantiles. It shows that the impact of energy innovation on income might be equitable, but it will be more prone towards being negative, or skewed.

4.2. Quantile-on-Quantile regression analysis

Following the QQ plot analysis, we will now proceed with analyzing the impact of distribution of Energy Innovation on Income distribution in N11 economies following the Quantile-on-Quantile regression (thereafter QQR) approach. We will analyze the results (in Figure 2) for the impact of energy efficiency on per capita GDP for the individual members of N11 countries one by one. The impacts of are indicated through the area combining the lower to higher quantiles of energy efficiency (i.e., 0.05-0.95) on the lower to higher quantiles of per capita GDP (i.e., 0.05-0.95).

<Place for Figure 2>

For **Bangladesh**, the effect of distribution of Energy Innovation of Income distribution remains in the area that combines the lower to upper quantiles of energy efficiency (0.05-0.95) with the lower quantiles to upper quantiles of per capita GDP (0.05-0.95). Negative impacts of Energy Innovation are visible from lower to middle quantiles (0.05-0.60) and positive impact on higher quantiles (0.65-0.90). At the 95th quantile, the impact turns out to be negative. Therefore, it might be possible that the distribution of energy innovation is not favorable at the lower and middle quantiles of income (citizens pertaining to poor and lower-middle class) and favorable at the upper quantiles of income (citizens pertaining to upper-middle class and rich). At the highest quantile, protection of innovation capabilities might create a divide between the richest people in the income strata. On the contrary, for **Egypt**, the effect of distribution of Energy Innovation of Income distribution remains in the area that combines the lower to upper quantiles of energy efficiency (0.05-0.95) with the lower quantiles to upper quantiles of per capita GDP (0.05-0.95).

Positive impacts of Energy Innovation are visible from lower to middle quantiles (0.05-0.60) and negative impact on higher quantiles (0.65-0.90). At the 75th quantile, the impact turns out to be positive. Therefore, it might be possible that the distribution of energy innovation is favorable at the lower and middle quantiles of income and unfavorable at the upper quantiles of income. Incidents of corruption and high cost of doing business impede the diffusion of energy innovation across sectors, and thereby, it creates the inequitable distribution of income at the higher income strata. Similarly, for **Indonesia**, the effect of distribution of Energy Innovation of Income distribution remains in the area that combines the lower to upper quantiles of energy efficiency (0.05-0.95) with the lower quantiles to upper quantiles of per capita GDP (0.05-0.95). Positive impacts of Energy Innovation are visible from lower to middle quantiles (0.05-0.55) and negative impact on higher quantiles (0.60-0.95). Therefore, it might be possible that the distribution of energy innovation is favorable at the lower and middle quantiles of income and unfavorable at the upper quantiles of income. While the initiatives like Mission Innovation has helped Indonesia to diffuse the technological solutions among the people from lower income strata, the issues of labor unrest is creating a disruptive distribution of income among the rich people. For **Iran**, the effect of distribution of Energy Innovation of Income distribution remains in the area that combines the lower to upper quantiles of energy efficiency (0.05-0.95) with the lower quantiles to upper quantiles of per capita GDP (0.05-0.95). Negative impacts of Energy Innovation are visible from across all quantiles, while the impact is less at middle quantiles (0.40-0.60). Therefore, it might be possible that the distribution of energy innovation is unfavorable at all quantiles of income, while the middle class might have been less impacted compared to the other strata of income.

For **South Korea**, the effect of distribution of Energy Innovation of Income distribution remains in the area that combines the lower to upper quantiles of energy efficiency (0.05-0.95) with the lower quantiles to upper quantiles of per capita GDP (0.05-0.95). Positive impacts of Energy Innovation are visible across all quantiles, except 30^{th}, 50^{th}, and 60^{th} quantile. The impact of innovation on income distribution is more towards the lower quantiles, and it denotes the equitable diffusion of energy innovation among the people from lower strata of income. However, this diffusion has not been favorable for the people from middle class. For **Mexico**, the effect of distribution of Energy Innovation of Income distribution remains in the area that combines the lower to upper quantiles of energy efficiency (0.05-0.95) with the lower quantiles to upper quantiles of per capita GDP (0.05-0.95). Negative impacts of Energy Innovation are visible at lower quantiles (0.05-0.10) and higher quantiles (0.65-0.95). The impact becomes positive at middle quantiles (0.15-0.60). The impact of innovation on income distribution is more severe towards the higher quantiles, and it denotes the policy level failure to diffuse the benefits of energy innovation either towards industrial sector, or towards marginalized people. However, this diffusion has been proven to be favorable for the people from middle class, and this might be an initial result of the clean energy investments by the Ministry of Energy, Mexico. Alongside these cases, Nigeria demonstrates a completely different picture, which is comparable to that of the case of Bangladesh. For **Nigeria**, the effect of distribution of Energy Innovation of Income distribution remains in the area that combines the lower to upper quantiles of energy efficiency (0.05-0.95) with the lower quantiles to upper quantiles of per capita GDP (0.05-0.95). Positive impacts of Energy Innovation are visible from low to high quantiles (0.25-0.95). The negative impact is visible at lower quantiles (0.05-0.20), and this impact in nearly minimal. This shows the effectiveness of Energy Innovation strategies in Nigeria to diffuse the benefits of innovation across all strata of income. As the country is gradually moving away from biofuel and waste-based energy solutions and embracing renewable energy solutions, they have been able to gradually lift the standard of living across the nation. The scenario in Pakistan is completely opposite to that to Nigeria. For **Pakistan**, the effect of distribution of Energy Innovation of Income distribution remains in the area that combines the lower to upper quantiles of energy efficiency (0.05-0.95) with the lower quantiles to upper quantiles of per capita GDP (0.05-0.95). Negative impacts of Energy Innovation are visible across all the quantiles. This shows the policy level ineffectiveness to diffuse the benefits of Energy Innovation strategies across the nation. Moreover, incidents of corruption and the energy crisis have impacted the production capabilities of Pakistan to a great extent, and this has resulted in an inequitable distribution of income among people, especially the upper strata of income. The situation at Philippines is not very different compared to that of Pakistan. For **Philippines**, the effect of distribution of Energy Innovation of Income distribution remains in the area that combines the lower to upper quantiles of energy efficiency (0.05-0.95) with the lower quantiles to upper quantiles of per capita GDP (0.05-0.95). Negative impacts of Energy Innovation are visible across all the quantiles, except 85th and 90th quantiles. The policy level ineffectiveness to diffuse the benefits of Energy Innovation strategies, incidents of corruption, and the energy crisis have impacted the production capabilities of Philippines, and this has resulted in an inequitable distribution of income among people. Rising inequality due to this scenario is causing the accumulation of wealth in few hands at the people from upper quantiles of income.

In terms of Energy Innovation, the performance of Turkey has been satisfactory among all the members of N11 countries. For **Turkey**, the effect of distribution of Energy Innovation of Income distribution remains in the area that combines the lower to upper quantiles of energy efficiency (0.05-0.95) with the lower quantiles to upper quantiles of per capita GDP (0.05-0.95). Positive impacts of Energy Innovation are visible across all the quantiles, with the impact higher at upper quantiles on income. This shows that the Energy Innovation has been well-diffused across the nation, while the people from upper quantiles of income are reaping more benefit from it. The scenario in Vietnam is nearly same, with some differences. For **Vietnam**, the effect of distribution of Energy Innovation of Income distribution remains in the area that combines the lower to upper quantiles of energy efficiency (0.05-0.95) with the lower quantiles to upper quantiles of per capita GDP (0.05-0.95). Positive impacts of Energy Innovation are visible across all the quantiles, with the impact higher at lower quantiles on income. This shows that the Energy Innovation has been well-diffused across the nation, while the people from lower quantiles of income are reaping more benefit from it, whereas the people from upper quantile of income are yet to fully realize its benefits.

In a nutshell, it can be seen that the diffusion or distribution of energy innovation across the members of N11 countries are different, and this difference in distribution is having an impact on the distribution of income. For Turkey, Vietnam, and South Korea, the distribution of energy innovation is fairly equitable and positive in terms of its impact on the distribution of income, whereas Iran and Pakistan have shown the impact to be negative all through the income distribution. For the remaining countries, the impacts have been found to be inequitable, as the impact of energy innovation on income distribution varies with its quantiles, and thereby demonstrating the flawed diffusion of innovation leading to unequal accumulation of wealth.

4.3. Robustness check

In order to ascertain the robustness of the QQR results, we have carried out Quantile Regression (QR) to assess the impact of distribution of Energy Innovation of Income distribution in N11 economies. As QQR decomposes the QR evaluations, hence QQR evaluations contain additional information compared to QR evaluations. Moreover, the indexation of QR is one level less than that of QQR, as QR assumes the quantiles of the explanatory variable. Outcome of QR approach are reported in Figure 3.

<Place for Figure 3>

For all the N11 member countries, the QQR assessment outcomes are plotted against the slope parameters of QR assessment, and it can be seen that the variations in these two aspects are nearly similar for all the countries, irrespective of the quantile distribution. Based on this result we can conclude that QQR outcomes are robust for all the countries under consideration.

5. Conclusion and policy implications

By far, we have analyzed the impact of distribution of Energy Innovation of Income distribution in N11 economies over 1990-2016. Objective of this study was to analyze how the distribution of energy innovation in a nation might have an impact on the income distribution, i.e. how energy innovation is playing a role in skewing the income distribution or shaping income inequality. As this issue might be more prevalent in the emerging and frontier nations with high prospect of economic growth, N11 economies make a suitable case for this study. In this pursuit, Energy Innovation has been denoted by energy efficiency, which has been calculated by Fisher Ideal Index. For assessing the impact, the QQR approach developed by Sim and Zhou (2015) has been employed. The study outcome has endowed us with an assortment of results across the nations, and these outcomes can be divided into three parts, namely (a) equitable and positive impact of distribution of energy innovation on the distribution of income, (b) negative impact of distribution of energy innovation on the distribution of income, and (c) inequitable impact of distribution of energy innovation on the distribution of income. All these three scenarios can divulge several policy implications for these nations.

Let us begin with the scenario of the countries with equitable and positive impact of distribution of energy innovation on the distribution of income. These nations are a step ahead of the other N11 member countries towards the achievement of SDG objectives. While saying this, it should also be noted that the countries under this stratum show certain level of skewing in their impacts, which might turn out to be a bigger issue at a later stage. In order to avoid this risk, the countries should first promote people-public-private-partnerships, so that citizens can be aware of the various energy innovations emerging within the nation, and these innovations can be replicated (Roy and Singh, 2017; Roy et al., 2018). For innovations to be accessible, government should make the business environment collusive, so that technology transfer can be easier, and new organizations can start operating. This initiative might help these nations to create more job opportunities, which will be reflected in the reduced income inequality (objective of SDG 10) and a better livelihood (objective of SDG 8).

However, these solutions might not be feasible for the countries in the second stratum, who demonstrate negative impact of distribution of energy innovation on the distribution of income. Economic growth of these nations still relies largely on the fossil fuel-based solutions, and therefore, replication and diffusion of energy innovations are difficult in these countries. Moreover, incidences of corruption might be another hindrance in the way of implementation (Shahbaz et al., 2019; Sinha et al., 2019). In order to address this issue, the legislative and regulatory framework for fostering energy innovation should be strengthened. In order to formalize this, the banks and other financial institutions should be directed to provide loans and advances to the organizations, based on their carbon or ecological footprint, i.e. discriminative interest rate mechanism should be followed for providing loans and advances. This will force the organizations to opt for energy innovations to reduce their negative environmental externality. This can be considered as a first phase of the policy framework for these nations by assuring energy innovation by bringing forth infrastructural reform (objective of SDG 9). Once this step is formalized, then the policymakers should ponder upon diffusing these innovations across the nation. In this pursuit, only generating environmental awareness through people-public-private-partnerships might not be sufficient, as these innovations might not be replicated without suitable business opportunities. Therefore, the policymakers should focus on easing business environment and reduce bureaucratic processes for allowing new business opportunities to open. Once this process is formalized, then rise in the job opportunities will start improving the living standard of the citizens enabled a decent income level (objective of SDG 8), while the energy innovations will help these nations to encounter the climatic shift (objectives of SDG 13). Once this phase is carried out, the policymakers should start amending the educational curriculums to provide more stress on the role of alternate energy and innovation (Sinha et al., 2017; Destek et al., 2020; Zafar et al., 2020). This educational reform through ensuring quality of education will help the implemented policies to be sustained at the grassroots level (objective of SDG 4).

These reform-oriented policies might not be necessary for the countries characterized by inequitable impact of distribution of energy innovation on the distribution of income. These nations should focus on the proper distribution of energy innovation across the nation, so that the distribution of energy innovation by means of diffusion can benefit the citizens from all the strata of income. In order to ensure this, the policymakers should focus on proper diffusion of energy innovations towards people from both upper and lower quantiles of income. For the people from lower quantiles of income, the ideas generated by them should be financially backed by the government, so that those innovations might be realized. In order to replicate those innovations, government should encourage people-public-private-partnerships, so that awareness regarding those innovations can be spread (Destek and Sinha, 2020). Moreover, the idea generators should be made anchors for replicating the ideas at the grassroots level. On the other hand, the firms should be encouraged to use energy innovations for replacing the fossil fuel-based energy solutions used by them. In this pursuit, the loans and advances disbursed to them should be discriminatively priced, based on the negative environmental externality created by them. This is when the government should ensure that the energy innovations fostered by these firms should not act as a direct replacement of labors, as this move might hinder the social sustainability of these nations. If these phases are implemented, then the nation will be able to provide decent income and livelihood to its citizens (objective of SDG 8), combat climatic shift (objective of SDG 13), and foster innovation thorough infrastructural reforms (objective of SDG 9). A detailed design of the framework has been provided in Figure 4.

<Place for Figure 4>

Before concluding the study, it is necessary to remember that any policy framework is not absolute in nature, as it might not be possible to encapsulate all the relevant control and target policy parameters within a single framework, and the policy framework suggested in this study is not an exception to that. This study has been carried out following a bivariate framework, and there lies the limitation of the study. In order to add dimensions to the study, the industrial aspects could have been considered. As the present study paves a baseline approach in determining the impact of distribution of energy innovation on income distribution, future developments on this line might bring forth additional insights by considering the spatial dimensions for elucidating the regional dependence.

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