Interplay between Technological Innovation and Environmental Quality: Formulating the SDG Policies for Next 11 Economies

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2020

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Abstract

Since the inception of Sustainable Development Goals (SDGs), the Next 11 (N11) countries are facing difficulties in attaining the SDG objectives, as maintaining the environmental quality has been a challenge for them. In this study, we have revisited the technology policies of these countries, and in doing so, we have tried to address the problem of environmental degradation, while addressing the issues of sustained economic growth, clean and affordable energy, and quality education. In this pursuit, we have designed two indices for environmental degradation and technological advancement, and then analyzed the association between them following the Environmental Kuznets Curve (EKC) hypothesis. The empirical analysis has been done by IPAT framework, and by using bootstrapped quantile regression and rolling window heterogeneous panel casualty tests, over a period of 1990-2017. Following the results obtained from the analysis, we have tried to address the objectives of SDG 13, SDG 4, SDG 8, SDG 9, SDG 7, and SDG 10.

Keywords: Sustainable Development Goals; Technology policy; R&D, Next 11; Environmental quality

1. Introduction

The United Nations mandate ("*Transforming our world: the 2030 Agenda for Sustainable Development*"), for implementation seventeen sustainable development goals (SDGs), was endorsed on 1st January 2016, with the objective of transforming the world through careful implementation of SDG's at the country level. The primary purpose of the mandate was to convince nations to unite and formulate strategies for sustainable industrial practices and living conditions. Unfortunately, the current state of affairs with regard to the progress made in different areas of SDG's remains questionable in view of the 2030 target agenda. According to the *Sustainable Development Goals Report 2018*, there has been contradicting results from different parts of the world (United Nations, 2018). The positive developments include: a) South Asia has reported a 40% decline in child marriages, b) access to electricity has doubled in least developed countries, and c) Sub-Saharan Africa has reported a decline of 35% in maternal mortality rate. However, there are contradictory evidences too which include: a) basic level of sanitation is still out of reach to 2.3 billion people, b) people practicing open defecation amounts to 892 million, and c) 90% of the people living in cities still breathe polluted air. In addition, reasons such as climate change, droughts and conflicts have increased the number of undernourished population to 0.815 billion in 2016 with an increase of approximately 4.89% from previous year.

Past research has suggested that tackling climate change (SDG 13) is one of the most challenging issue persisting in both developed and developing nations, and as a result, contrasting policy directives have emerged in plenty (Baumeister 2018, Bisbis et al. 2018, Sinha et al. 2018). The issue attracts more importance owing to the alarming levels of carbon emissions predicted for 2018 (Figueres et al. 2018; Quéré et al. 2018). Further, the highest five-year average global temperatures were recorded for the period 2013-2017 by the World Meteorological Organization. One of the obvious solutions to climate change mitigation is the use of clean energy (SDG 7: Affordable and Clean Energy). The current trend, as suggested by the 2018 Sustainability report, show that renewable energy is expected to reach only 21% of the total energy consumption by 2030. The adoption rate is subject to many factors such as economic growth (SDG 8), foreign direct investment towards green technologies and internal microeconomic and macroeconomic policy of a country for a given period. With the belief that clean energy is an important part of sustainable energy policy, nations need to invest in R&D and innovation towards green technologies in order to take advantage of clean energy. This needs to happen as a policy measure both in the short and long run for the economy. Hence, we need to address SDG 9 (Resilient Infrastructure, Sustainable Industrialization and Foster Innovation) to tackle the issue of SDG 7 in order to address SDG 13. We believe that this could be only possible when overall environmental awareness (SDG 4) is enhanced through quality education right from the start. The report shows that medium and high technology sectors still remains underutilized (44.7% for developed countries and 34.6% for developing countries of total manufacturing value) in 2015. This suggests that there is a huge opportunity to invest in green technologies and tap full market potential of the sector. Further, 617 million children are still deprived of minimum proficiency in reading in primary schools highlighting the void in education system leading to lower levels of environmental awareness. To summarize our argument, integrating SDG's should be an immediate response as a policy measure to tackle climate change without hampering economic growth of a region.

Evidence of a multi-pronged approach towards issues pertaining to SDGs is very scant (Le Blanc, 2015). The major reason behind this three-pronged SDG approach is that the impact of technological advancements are directly seen on the economic growth, and the benefits of economic growth are consequently seen in the further developmental processes. Therefore, the impact of technological advancement on developmental process is indirect, and any attempt to measure this impact might be deemed as far-flanged or overreaching. Considering these three SDGs as the starting point, we have tried to connect the other SDGs under a broad policy framework. For instance, existing studies on SDGs focus on creating index and dashboard (Sachs et al., 2017), diagnostics framework (Gable et al., 2015) and scorecards (Nicolai, 2015). To address this void, this paper analyzes the impact of technological development for environmental quality. We develop two different indices i.e., technological index and environmental index, to achieve our objective. We consider all major air pollutants under environmental index that include greenhouse gases. In the case of technological development, we have included factors such as intellectual property, patent, and technical cooperation, among others. We further adopt the EKC hypothesis framework for our empirical pursuit (for more details, see Shahbaz and Sinha, 2019). This ensures better policy implications in terms of capturing the behavior of predictors in our model. Figure 1 and 2 depict the movement of technological progression and ambient air pollution in the N11 countries. From Figure 1, it is visible that though the technical cooperation grants have been reduced over the years, the patent and trademark applications have increased, thereby, indicating the growth in technological progression in these nations. On the flipside, Figure 2 demonstrates the rise in ambient air pollution in these nations, as most of the ambient air pollutants under consideration have shown upward trend during the study period. This basic diagrammatic representation of the model parameters can create a basis of our study, which is focused on assessing the impact of technological progression on environmental quality in the N11 countries.

<Insert Figure 1 here>

<Insert Figure 2 here>

We purposefully chose Next 11 or N11 countries (Bangladesh, Egypt, Indonesia, Iran, South Korea, Mexico, Nigeria, Pakistan, the Philippines, Turkey, and Vietnam) as the unit of analysis for several reasons. First, the N11 countries are one of those emerging markets that have the potential to become one of the world's largest economies. These countries are often referred as the "next BRIC economies". As a result, these countries have the potential to surpass and pose as a rival to the current leading economies in the world. However, there are certain contextual challenges with respect to the growth prospects in these regions. For instance, Nigeria is working to bring down corruption; Turkey has struggled to integrate itself into European Union; Pakistan has been busy reforming its banking and taxation laws. Second, with respect to environmental impact, as and when these countries become more industry intensive and less energy efficient to foster economic growth, environmental issue will creep in. Although countries such as Nigeria and Mexico are taking steps to reduce the negative impact of environmental degradation by improving their energy intensity, it will be essential to pursue a multi-pronged strategy to counter environmental change without harming economic growth. This concern is motivated by the fact that N11 and BRIC countries contribute to more carbon emissions than other leading economies in the world. Third, in terms of technology, innovation and R&D, N11 countries have shown mixed results. For instance, countries like Korea and Turkey have rivaled BRICS nations such as Russia and Brazil in terms of phone penetration, other countries have shown less-promising results. However, the poorer countries have shown outstanding performance in terms of growth rate thus highlighting the potential of infrastructure, technology, R&D and innovation in such nations[1]. However, there is no evidence for such factors that can positively contribute to environmental quality without compromising on economic growth.

We have structured the subsequent sections in the following manner: Section 2 summarizes the research gap by presenting an overview of the literature on R&D, Innovation and technology and its relationship with environmental quality. Section 3 explains the mathematical model and the theoretical framework for the study. Section 4 presents the results of the econometric analysis. Section 5 details the research, practice and policy implications of this paper. Section 6 concludes our study by explaining how our paper addressed the research questions as stated in the first section.

2. Literature Review

We present our literature review in three parts. The first part discusses on the literature concerning R&D, technology, economic growth, innovation and population on environmental quality. The second part focuses on the interplay of technology and SDG on one hand and SDG and climate change on the other hand. The third part triangulates the literature on both these subsections and presents the research gap for our study.

2.1. Innovation, Economic Growth, Population and Environmental Quality

Studies involving technology policy and carbon emissions have developed over the last decade. The first few studies looked into the impact of research and development (R&D) on carbon emissions and

[1] https://www.goldmansachs.com/insights/archive/archive-pdfs/brics-book/brics-chap-13.pdf

economic growth in developing countries (Fisher-Vanden and Wing, 2008). Extending on similar lines, researchers studied the linkages between R&D investments in the energy sector and environmental quality in select developed economies. Then came studies related to regulations, environment and technology policy (Lewis, 2016). For instance, Yi (2012) explored the role of environmental regulation and innovation arising out of technology in reducing carbon emissions in China. Also, there were studies which looked at different aspects of technology. For instance, Li et al. (2018) explored the impact of high-technology towards growth and emissions by conducting a spatial model for 30 provinces in China. Similarly, there are studies which explored ICT and its relationship with carbon emission (Shabani and Shahnazi, 2019; Sinha, 2018). Then there were generic studies which looked into the aspect of technology and innovation towards environmental quality (Fortune, 2019; de Vries and Ferrarini, 2017; Irandoust, 2016).

There are very few evidences, where authors have used innovation and R&D as a combined technological parameter in estimating their linkages towards environmental quality (Apergis et al., 2013; Álvarez-Herránz et al., 2017a, b; Churchill et al., 2019). Further, studies involving technology and carbon emissions (Bond et al., 2004; Gelenbe and Caseau, 2015; Wolfram and Lutsey, 2016) have neglected two aspects which provides us the following research gaps, First, there is very little evidence (Zongzhi, 2010) to the best of our knowledge that has included technology, environmental policy, economic growth and population in one paper. Second, the literature did not take the help of the EKC framework to understand the policy level implications especially in the long run. Our paper contributes to this research void by analyzing a robust technological policy while designing both environmental and technological index in one study.

2.2 Technology, SDG, and Climate Change

Studies concerning SDG’s and climate change have been diverse in terms of its focus and the issues it has addressed in the literature (Ladan, 2018; Major et al., 2018; Shahbaz et al., 2019). Kelman (2017) focus on the need to include climate change mitigation strategies with disaster risk management and attempts to link such strategies to different SDG’s. On similar lines, Kedir (2017) highlight the need to climate change mitigation strategies in Africa in order to prevent worsening of food security and thereby help in achieving SDG targets in specific domains. Here the author stresses on the need to use modern technology to achieve its objectives. Reckien et al. (2017) highlights the importance of the climate change impact to urban population and subsequent consequences to different SDG’s. Balasubramanian (2018) again stressed on the need to look into climate change and risk of famine in marginalized communities thereby contributing important aspect of SDG’s. However, we have observed that very scant evidence exists on the role of technology as a policy to address climate change and its associated SDG’s.

With regard to the interface between technology and SDG's, most of the studies are focused on mutually exclusive themes. For example, Adams et al. (2018) analyzed the role of blockchain technology in delivering environmentally and socially beneficial outcomes to challenging business models thereby contributing to the UN SDG's. Van der Sanden (2018) explored the synergy between space technology in achieving sustainability in different aspects benefiting life on earth by examining different focus areas within the 17 SDG's. Then there were studies which highlighted the importance of technology as an effective tool towards achieving the SDG targets (Imaz and Sheinbaum, 2017). Similarly, Dialoke (2017) analyzed how technology in the education sector in Nigeria can be utilized in achieving SDG targets. However most of the studies are very diverse and as a result there remains a void in explaining a robust and structured technology policy in achieving different SDG's.

2.3 Research Gap

Triangulating our discussion from above, we argue that there are three research gaps that our paper wishes to address. First, there are negligible evidence which analyze technological policy and environmental quality from the umbrella of EKC hypothesis. Second, there is no evidence in the literature that formally integrates different SDG's to recommend policy level decisions. The importance of this claim has been recently documented in the literature (Le Blanc, 2015). Third, there are very few literatures which have addressed the linkages between technology and SDG's at the policy level, thereby providing an opportunity to address the same in our study. Our paper attempts to contribute two areas in the body of literature. First, this paper revisits technology policy as a mean to address short run and long run forecasts through the EKC hypothesis in N11 countries. This provides an opportunity for researchers to conduct replication studies in other developing and emerging nations and provide sound policy decisions towards the interplay of clean technology and economic growth. Second, our paper is one of the first to analyze environmental quality and technology policy by designing and integrating two different indices which covers a comprehensive list of technological advancement (intellectual property, patents, and technological cooperation) and environmental degradation parameters (all major pollutants including greenhouse gases).

3. Theoretical Model and Data

This research intends to analyze the effect of technological advancements on environmental quality for the N11 countries over the period of 1990-2017. In order to analyze this impact, we have considered the IPAT framework developed by Ehrlich and Holdren (1971). The mathematical model to be estimated in this study has been developed in accordance with the standard literature of EKC hypothesis and IPAT framework (see Paramati et al., 2017; Sinha and Sengupta, 2019). Following is the model:

$$ENV_{it} = f(GNI_{it}, GNI_{it}^2, TECH_{it}, REN_{it}, POP_{it}) \quad (1)$$

Where, *ENV* is the index of ambient air pollution, *GNI* is the gross national income, *TECH* is the index of technological progression, research and development, *REN* is the renewable energy consumption, *POP* is the population, *i* is the countries considered in the study (*i* = 1, …, N) and *t* is the study duration (*t* = 1, …, T).

Now, ENV is constructed by considering five major air pollutants of N11 countries, i.e. carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), particulate matter 2.5 (PM2.5), and other greenhouse gases (GHG_O), including hydrofluorocarbons (HFC), perfluorocarbons (PFC) and sulfur hexafluoride (SF_6). Similarly, TECH is constructed by considering three major research and development indicators, i.e. number of patent applications (PAT), number of trademark applications (TM), and technical cooperation grants (GR). Both of these indices are constructed using principal component analysis (PCA).[2] One of the major reasons for using these indices is that focusing only on either local or global pollutants might not bring forth the accurate picture of the degradation of ambient air quality in these countries. On the other hand, owing to the differing level of development, the level of research and development in these countries vary largely, and therefore, choosing one single indicator for research and development might not depict the true picture of technological innovation and progression in these nations. Therefore, these two indices can be indicated as per the following (eigenvalues of the indices are provided in Figure 3):

$$ENV_{it} = \alpha_{0it} + \alpha_{1it}CO_{2_{it}} + \alpha_{2it}CH_{4_{it}} + \alpha_{3it}N_2O_{it} + \alpha_{4it}PM2.5_{it} + \alpha_{5it}GHGO_{it} + \epsilon_{it} \quad (2)$$

$$TECH_{it} = \beta_{0it} + \beta_{1it}PAT_{it} + \beta_{2it}TM_{it} + \beta_{3it}GR_{it} + \epsilon_{it} \quad (3)$$

<Insert Figure 3 here>

Saying this, let us look back at the IPAT framework to operationalize the mathematical model given in Eq. (1). Going by the description of the framework, the association between environmental impact (I), population (P), level of economic activity (A), and technology (T) can be shown as:

$$I = P \times A \times T \quad (4)$$

This model implies that the environmental quality is impacted by the population, level of economic activity, and the level of technology used. However, Dietz and Rosa (1994, 1997) devised the STIRPAT (Stochastic Impacts by Regression on Population, Affluence, and Technology) model, which can be empirically analyzed. Our model in Eq. (1) is developed in the similar lines with this framework, where ENV represents ambient air pollution, GNI and REN are considered as the proxies of economic activities and affluence, TECH is the proxy of technological progression, and POP is considered as population. In continuation with the discussion, the empirical model of Eq. (1) can be denoted as per the following:

$$ENV_{it} = \theta_{0it} + \theta_{1it}GNI_{it} + \theta_{2it}GNI_{it}^2 + \theta_{3it}TECH_{it} + \theta_{4it}REN_{it} + \theta_{5it}POP_{it} + \epsilon_{it} \quad (5)$$

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[2] Results are available on request.

In the empirical analysis, as a first step, we have checked the cross-sectional dependence in the data by using the weak cross-sectional dependence test devised by Chudik and Pesaran (2015). The theoretical and empirical econometric literature has shown that there may be unobserved dependencies between the transversal units (Pesaran, 2007; Chudik and Pesaran, 2015). Liddle and Lung (2014) argue that most models with panel data tend to be intrinsically dependent on cross sections. Chudik and Pesaran (2015) show that the consistency of estimator improves, when a component is added that captures the delays of the averages of the cross section. Depending on the result of this particular test, we have applied the Breitung (2001) and Herwartz and Siedenburg (2008) unit root tests. These unit root tests are second generation in nature, i.e. these tests assume the cross-sectional dependence in the data. It is possible that the models with panel data have a trend component when incorporating time series and cross section data. Therefore, it is necessary to ensure that the variables are stationary before the cointegration tests. Also, first generation unit root tests are not valid when there is dependency on the cross sections, and consequently, we use second generation unit root tests, specifically, the Herwartz and Siedenburg test (2008). This test assumes the existence of a common factor with the same effect in all countries. An advantage of the second-generation tests is that they implicitly capture the possible cross-section dependence, in which case a test that allows the presence of transversal dependence patterns is preferable (Pesaran, 2007), particularly when cross sections and time series are small. Once we found the order of integration among the variables, we have checked for the long run cointegrating association among the variables, and in doing so, we had to consider the issue of cross-sectional dependence. Therefore, we have applied the Westerlund and Edgerton (2008) panel cointegration test. This test verifies the null hypothesis of non-cointegration and allows cross section dependence, unknown structural ruptures within the heterogeneous panel, either at the intersection or in the slope of the cointegration regression, which can be located in different periods in any of the units of analysis, which are characteristic in the panel data. The Westerlund and Edgerton test (2008) is based on the unit root tests of the Lagrange multiplier (LM).

Now, it can be assumed that the level of ambient air pollution might not be equal in all the countries, and therefore, the consequential developmental strategies will also have to be designed in accordance with the emission pattern. Owing to this reason, we have analyzed the impacts of affluence, population, and technological progression on ambient air pollution across its quantiles, by applying the quantile regression (Koenker, 2005). As robustness check, we also have applied mean group (MG), mean group with common correlated effects (CCE-MG), and augmented mean group (AMG) tests to analyze the mentioned association. Lastly, in order to bring forth more insights to the policy-level suggestions, we have applied rolling window heterogenous panel causality test (based on Balcilar et al., 2010; Dumitrescu and Hurlin, 2012). This test has been applied between ENV and TECH, and this test also adds one more level of robustness check on the environmental impacts of technological progression.

For this study, data has been collected for CO_2 emissions in thousand metric tons, CH_4 emissions in thousand metric tons of CO_2 equivalent, N_2O emissions in thousand metric tons of CO_2 equivalent, mean annual exposure of PM2.5 emissions in micrograms per cubic meter, other greenhouse gas emissions (i.e. HFC, PFC and SF_6) in thousand metric tons of CO_2 equivalent, GNI in current USD, technical cooperation grants in current USD, per capita renewable energy consumption in billion kWHs, number of patent applications, number of trademark applications, the total population, and the World bank indicators is the source of data for this study (World Bank, 2018), for N11 countries over a period of 1990-2017. In Table 1, we have added the descriptions of all the variables and the relevant literature for those variables. For the purpose of analysis, we have converted all the variables into natural logarithmic form, for making the data even, calculating elasticity, and to control the possibilities of heteroskedasticity.

<Insert Table 1 here>

4. Analysis of Results

In order to verify that there is no collinearity between the variables of the model, namely: technological progress (TECH), gross national income (GNI), population (POP), renewable energy consumption (REN) and pollution of the air (ENV), we apply the variance inflation factor test (VIF). The VIF captures the fact that as the coefficient of partial correlation between the pairs of variables increases, the variance and the covariance of the estimators also increases. When the partial correlation coefficients approach unity, the VIF approaches infinity, and, therefore, the variance and covariance grow indefinitely, making the estimators inconsistent and unbiased. In practice, the econometric models with panel data estimated in this research reduce collinearity and ensure that there is no dependence on the cross sections. The results of Table 2 show that after the transformation of the variables, the VIF tends to unity, which suggests that the collinearity between the pairs of variables is no longer a problem for subsequent econometric estimations.

<Insert Table 2 here>

In order to ensure that the variables used in the estimates do not have the problem of weak dependence on the cross sections, we used the Chudik and Pesaran test (2015). This test verifies the null hypothesis of the cross-section independence of the data. The results reported in Table 3 allow accepting the null hypothesis of the cross-section dependence of the variables. Dependence in the cross sections implies that the impact of a shock in one of the countries in the panel affects the other countries included in the sample. Similar recently published empirical studies have used the Chudik and Pesaran (2015) or similar test to verify that dependence on the cross sections is absent in the models (Zhang, et al, 2017, Churchill et al., 2019).

<Insert Table 3 here>

After the confirmation of the cross sectional dependence test results, we have moved carried out the second generation unit root tests. The results of the Herwartz and Siedenburg (2008) test are contrasted with an additional unit root test, the parametric test of Breitung (2000). The results obtained in these tests in levels and in first differences are reported in Table 4. The results of both tests confirm that the series in levels are non-stationary, while the first differences of the variables are stationary. All variables have the same order of integration I(1), that is, they become stationary variables by obtaining the first difference.

<Insert Table 4 here>

After the second-generation unit-root test points out that the variables do not have the unit root problem, we apply the cointegration test between the variables using the procedure proposed by Westerlund and Edgerton (2008). Since the results of Table 5, the null hypothesis of non-cointegration between the variables can be rejected. Therefore, it can be concluded that there are long-term equilibrium relations between technological progress, gross national income, population, renewable energy consumption and air pollution.

<Insert Table 5 here>

In addition to the cointegration results presented in Table 5, we performed the cointegration test of Westerlund and Edgerton (2008) in the presence of structural breaks. The tests of Westerlund and Edgerton (2008) with structural rupture allow the existence of dependence of the cross sections and that the errors are heteroscedastic and there is serial correlation. The results of Table 6 confirm the existence of cointegration after including structural breaks in the variables. We report the years of structural break no shift, mean shift, and regime shift. In practice, structural breaks can occur if shocks to the series cause a permanent and significant change. Structural breaks can be abrupt and gradual. Significant changes in policy and gradual changes in technological progress are an example of such breaks. In the countries analyzed, the mean Shift occurs between 1994 and 1997, that is, in a period of 3 years; which suggests that it is possible that the structural rupture was caused by a common factor. Recent empirical research highlights the importance of including structural breaks in the relationship between variables in panel data (Churchill et al., 2019, Hamit-Haggar, 2016). According to World Bank World Development Indicators statistics (2019), the GDP of a part of the analyzed countries experienced a decrease after 1994, in particular Asian countries, which may explain the structural break found around these years.

<Insert Table 6 here>

The levels of air pollution are associated with the productive structure of the countries, especially with the participation of manufacturing in the output. In general, a country with greater economic activity pollutes more, particularly when it is more industrialized. Also, environmental regulation on production processes, technology and pollution management; the population size, and the type of energy source are factors that significantly affect the levels of air pollution (Wang et al., 2019; Zeng et al., 2019; Li et al., 2019). In order to assess the differences between the levels of air pollution, the quantiles of air pollution were classified as low, medium and high. In this research, panel quantile regression describes the conditional quantile of air pollution in the face of changes in the technological progress, gross national income, population, and renewable energy consumption. The panel quantile regression (PQR) methodology estimates the model parameters at different points in the air quality distribution. The PQR allows obtaining more efficient estimators than those obtained through OLS, particularly when the error term is not normally distributed. Another advantage of the PQR estimators over the OLS is that the average regression procedure does not consider the effects that can be of a potentially heterogeneous nature. A possible limitation of the PQR methodology occurs, when there number of fixed effects is large. However, the number of cross sections in our study is relatively small. Table 7 reports the results of the regression quantiles proposed by Canay (2011), and Figure 4 shows the plot of quantiles at 95% level. The findings show that, the effect of gross national income is negative between quantiles 1-4, while the effect is positive in quantiles 5-9. With the exception of quantile 1, the coefficients are statistically at 1%, 5% or 10%, respectively. An interesting result of the squared GNI is that the quadratic effect is positive up to quantile 4 and becomes negative from quantile 5. Likewise, we find that the effect of technological progress on air quality is negative up to quantile 5, while from quantile 6 the effect is positive. With regard to non-renewable energy consumption, the effect on air quality is negative until quantile 4 and then becomes positive. Finally, the effect of the population on air quality is positive in all the quantiles. In general, the results obtained justify the adoption of the PQR because the effects of the independent variables are heterogeneous among the distribution of air quality.

<Insert Table 7 here>

<Insert Figure 4 here>

Additionally, the results of the PQR suggest that the functional form of the EKC changes according to the level of air pollution. From quartile 1 to 4, where air pollution levels are low, the shape of the EKC has a U-shape, while from quartile 5 to quartile 10 the EKC has a U-inverted shape.

<Insert Table 8 here>

The existence of a long-term equilibrium relationship between the variables of technological progress, consumption of renewable energy, population and air pollution that was reported in Table 5, allows estimating the long-term elasticities, which are reported in Table 8. In order to ensure the robustness of the estimators, the MG (mean group), AMG (Augmented Mean Group), CCE-MG (Common Correlated Effects Mean Group) models were estimated, which were formalized in the econometric strategy. The results show that all the elasticities are statistically significant at 1%, 5% or 10%, with an extremely large turning point. For the validation of the EKC hypothesis, the parameters associated with the GNI have the expected signs, evidencing the existence of an inverted U form for the N11 countries. Based on the results of the three regressions, the MG, AMG and CCE-MG estimators validate the EKC hypothesis in the 11 countries included in the sample. A relevant result is that as technological progress increases by 1%, air pollution increases between 0.02% and 0.07%. In this research, the variable technological progression is an index that measure of number of patent applications, trademark applications, and technical cooperation grants in current USD, which is reasonable that occurs in countries with greater industrial capacity and greater capacity for technological absorption. The industrial capacity and the accumulation of human capital that generates more technological progress, can be associated with the increase of the product, consequently, the long-term relationship between technological progress and air pollution is positive.

Another of the results of interest reported in Table 8 is that the consumption of renewable energy has a negative and statistically significant effect on air pollution. When the consumption of renewable energy increases by 1%, air pollution index reduces by 16-29%. This result is encouraging for the objectives of reducing air pollution in the countries analyzed with policy implications for other countries. Hence, public policies must promote the generation and consumption of energy from renewable sources to reduce the emissions of polluting gases that are mainly evolved in the air. Finally, the long-term effect of the population on air pollution has the expected sign, that is, it is positive in the three regressions. This result is consistent with the findings found by research that analyzes the determinants of air pollution (Li et al., 2017, Zhao et al., 2018).

Lastly, we have conducted the rolling window heterogeneous panel causality test between TECH and ENV. Bidirectionality is an inherent nature of any national level policy, those are targeted at sustainable development, and various researchers have identified this issue (Lu et al., 2014; Sinha et al., 2018). The results are shown in Figure 5, and it can be seen that the causal impact of technological progression on ambient air pollution is positive, whereas the reverse causal impact is also positive. This segment of results shows that on one hand the existing R&D activities are pro-industrialization, and the negative ecological impacts of these activities on the existing R&D activities are also significant. Presence of bidirectionality between these two aspects can prove to be a major concern for the policymakers in these nations.

<Insert Figure 5 here>

5. Discussion and Policy Implications

Through the course of analysis, we have observed the effect of technological progression, GNI, renewable energy consumption, and population on ambient air pollution in N11 countries, and this analysis brings forth a wide range of acumens in front of us. We can see that the technological progression exerts negative impact on ambient air pollution for low and medium quantiles and this impact turns out to be positive for higher quantiles. At the same time, renewable energy consumption is found to have negative effect on ambient air pollution across all quantiles. The N11 countries have been experiencing high income growth, and this growth is a result of the rapid industrialization in these nations. Hence, it can be said that the environmental policies and the technological innovations in these nations are majorly targeted at achieving industrial growth, which is attained even at the cost of environmental quality by creating ambient air pollution in these nations. The growth in national income and ecological deterioration are both being caused by the technological innovations taken up in these nations, and this is expected to have consequences on the sustainable development of these nations. In this view, the existing policies in these nations need to be restructured for internalizing the negative externalities caused by the growth trajectory and ensuring sustainable development.

In continuation to this discussion, it should not be forgotten that high implementation cost of renewable energy solutions might hinder the economic growth in several ways. If the policymakers start implementing the renewable energy solutions throughout the nation, then the nation will not only experience difficulties regarding high fiscal burden, but it might also make the existing energy infrastructure unnecessary. In order to avoid such a situation, the nations should ponder upon intrinsic development of innovation capabilities to ensure the sustainability from both economic and ecological perspective. Now, these developmental policies would differ based on the levels of ambient air pollution, i.e. low, medium, and high levels. We will start discussing these policies with the countries with low air pollution index. As these countries have demonstrated their ability to reduce the emission level, therefore further assistance from the policymakers will complement these efforts. In this pursuit, channelizing of financial resources for research and development in innovating renewable energy solutions is required with a view to substituting the prevailing fossil fuel-based solutions. Yet, mere substitution of production processes might prove to be effective in presence of sufficient environmental awareness among the citizens. Now, in order to institutionalize this awareness, the educational curriculums should be transformed for bringing forth the aspects of sustainable development. This rise in the level of awareness might eventually enhance the level of energy efficiency and reduce the demand for fossil fuel-based solutions. This phenomenon might induce the policymakers to apportion the economic resources by putting sustainable development ahead of economic growth. These developmental policies might enable these nations to attain the objectives of SDG 7 (clean and affordable energy) and SDG 4 (quality education), and accomplishment of both these objectives will help to achieve the objective of SDG 13 (climate action). Thus, the transformation from non-renewable to renewable solutions might be hassle-free, and by keeping the economic growth trajectory intact. Subsequent to this, we will analyze the situation for the countries with medium level of air pollution index. As these countries are in the transition phase from low to high air pollution, therefore, government supports for renewable solutions should be complemented by environmental taxation policies. The latter would be acting as enforcement and motivation factor for the industries to implement cleaner production processes via renewable energy solutions. Through this process, the demand for the green solutions might rise, and in order to sustain this demand in the economy, certain level of environmental awareness among citizens is necessary. This increase in the awareness can be institutionalized through the transformations in educational curriculum, by incorporating the aspects of sustainable development. Elucidation on these aspects will empower these nations to bring forth technological innovations for conception of green jobs and shrinking environmental degradation. These policy level transformations might help these nations to achieve the objectives of SDG 8 (decent work and economic growth) and SDG 9 (industry, innovation and infrastructure), along with fulfillment of the objectives of SDG 7 (clean and affordable energy) and SDG 4 (quality education), and SDG 13 (climate action).

Finally, we will discuss about the countries with high air pollution index. These countries are also recognized for rising population, energy inefficiency, and social differences. Owing to these factors, the developmental policies to be devised for these nations require being inclusive in nature. In this pursuit, these policies should be aimed at both industries and households. They can avail the renewable energy solutions from the governments at differentiated prices, and the solutions can be availed against loans. Government might introduce price discrimination for the solutions to be provided to these two parties, as the solution should be made cheaper for the households. Now, the loss of revenue from the households can be covered by the interest income received from the industries. In this way, the renewable energy solutions will be subsidized for households. While doing this, the government should also take care of the income level of the household for deciding upon the level of pro-rata price of the solutions to be provided to them. Like the previous two cases, these policy interventions should be completed by bringing forth transformation in the educational curriculums, as it will help in enhancing the level of awareness among the citizens. Moreover, through these policy interventions, technological innovations will be encourages at the foundation level, and that might result in the increase in green jobs. When the vocational opportunities will rise, the citizens will be having higher level of income, superior standard of living, better access to education and healthcare, higher environmental awareness and energy efficiency, and thereby, the nations will be moving towards sustainable development. When these aspects of economy are stabilized, it is expected that the social disparity might be reduced. Moreover, boost in employment prospects might lead to reduction in income inequality. As identified by Sinha and Bhattacharya (2016b), policies targeted at improvement of energy efficiency can possibly have a positive spillover effect. When these developmental policies are implemented, these nations will be able to achieve the objectives of SDG 8 (decent work and economic growth), SDG 9 (industry, innovation and infrastructure), SDG 7 (clean and affordable energy) and SDG 4 (quality education), and SDG 13 (climate action), and as we have discussed, fulfillment of these objectives will automatically lead towards partial fulfillment of the objective of SDG 10 (reduced inequality).

As a whole, the policymakers of the N11 nations should ponder upon bringing forth the technological innovations through R&D in quest of diminishing ambient air pollution, designing energy efficient and green technologies, and generating new employment prospects. Alongside implementing these policies, the policymakers should also focus on the discovery of renewable and alternate energy solutions, and encouraging environmental awareness through transforming the educational curriculum. For making the implementation process smooth and hassle-free, the policymakers should consider both industries and households, as this consideration might help the policymakers to sustain the economic growth trajectory unharmed. The price discrimination should be carried out for industrial and domestic consumers, and within the strata of domestic consumers, further price discrimination should be done based on the income level of households. This forceful discrimination will help maintaining the parity during the implementation process. While enhancing the level of environmental awareness among the citizens, policymakers should also encourage the people-public-private-partnerships, so that the awareness can reach the grassroots level. Implementation of these policies should be able to lessen environmental degradation (achievement of SDG 13), increase environmental awareness through transformation in educational curriculum (achievement of SDG 4), nurture innovation and create employment prospects through R&D activities (achievement of SDG 8 and 9), making green and clean energy affordable (achievement of SDG 7), and reduce social imbalance and income inequality through improvement in quality of life (achievement of SDG 10). Levels of SDG achievement are detailed in Appendix 1.

6. Conclusion

The negative externalities caused by the seamless growth trajectory achieved by the nations has given birth to the concern of attaining sustainable development, and manifestation of this issue at a global scale has led to the formulation of the SDGs. N11 nations are characterized with high growth and industrialization, and the growth trajectory attained by them might prove to be unsustainable in nature. Therefore, the existing policies in these nations need to be redesigned so as to align with the SDG objectives, so that these nations can achieve them by 2030. This study takes a step towards that objective. In this study, we have observed the effect of technological progression, GNI, renewable energy consumption, and population on ambient air pollution, following the generally accepted EKC framework. Through bootstrap quantile regression analysis, we have analyzed this association for countries with low, medium, and high air pollution, and using MG, CCE, and AMG analysis, we have carried out the robustness check. Last of all, rolling window heterogenous panel causality test between technological progression and environmental degradation has been employed. Founded on the outcome of the empirical pursuit, we have recommended a set of policies to address the objectives of some of the SDGs. This study has shown that in order to achieve the reduction in inequality, the nations should start making the energy clean and affordable for the citizens and strengthening the environmental policies. While ensuring the environmental aspects, policymakers should create employment prospects through R&D activities. When these aspects will be in place, environmental awareness should be created through transformations in educational curriculum, along with encouraging innovation. With these things in place, the nations will be able to create enough employment prospects, which will in turn improve the living standard of the citizens. This improvement in livelihood conditions will not only reduce the income inequality, but also might reduce social imbalance. This policy framework might help these nations in achieving the objectives of several SDGs.

Considering the context of N11 countries, this is the first study to take a comprehensive approach towards policy recommendations for achieving the SDG objectives, while deliberating technological progression as a catalyst of sustainable development. Developing the indices for ambient air pollution and technological progression has given us the scope to look beyond a single indicator for both of these parameters, and thereby providing us the flexibility to devise the policies in a wholesome manner. In the literature of environmental economics, introduction of these indices can be considered as a contribution. Lastly, application of quantile modeling helped us in identifying the nations with different levels of ambient air pollution, and thereby, giving us the scope to design the policies in a more targeted manner. Methodological application of the study helped in setting the context of the study in a more detailed manner. Lastly, from the perspective of policymaking, our study has contributed to the literature of ecological economics by demonstrating the implementation pathways for achieving the SDG objectives, and how the technological innovation can act as a catalyst in this implementation process.

As a closing note, it is needed to be stated that robust policy design calls for availability of data, and in the context of N11 countries, data availability is one of the major issues identified by several researchers. Owing to this problem, we were not able to several other indicators of technological progression in this study. Consequently, we would like to mention that one of the limitations of the study is the unavailability of the data.

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