Carbon Tax and Energy Innovation at Crossroads of Carbon Neutrality: Designing a Sustainable Decarbonization Policy

Cheng, Ya and Sinha, Avik and Ghosh, Vinit and Sengupta, Tuhin and Luo, Huawei

Sichuan Agricultural University, Chengdu China, Goa Institute of Management, India

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Ya Cheng
College of Management,
Sichuan Agricultural University, Chengdu China
Email: fightgod008@163.com

Avik Sinha
Centre for Excellence in Sustainable Development,
Goa Institute of Management, India.
Email: f11aviks@iimidr.ac.in

Vinit Ghosh
Department of Organisational Behaviour & Human Resource Management,
Goa Institute of Management, India.
Email: vinit@gim.ac.in

Tuhin Sengupta
Centre for Excellence in Sustainable Development,
Goa Institute of Management, India.

Department of Information Technology and Operations Management,
Goa Institute of Management, India.
Email: f13tuhins@iimidr.ac.in

Huawei Luo[1]
College of Management
Sichuan Agricultural University, Chengdu China
Email: 3115059778@qq.com

Abstract

Decarbonation has been a primary policy prerogative for Sweden, and carbon tax has been a primary policy instrument in this pursuit, and the revenue generated out of carbon tax has been a driver for energy innovation. However, the benefits of energy innovation have not been experienced across various sectors in Swedish economy, and it might be anticipated that the potential aim of achieving carbon neutrality might not be accomplished to the fullest. Hence, being faced with the need of policy realignment for Sweden, this study has made an attempt to discover the dynamics between carbon tax revenue and energy innovation over a period of 1990-2019, following Quantile-on-Quantile Regression framework. The results obtained from the study show that the impact of carbon tax revenue on energy innovation might turn out to be ineffective beyond a certain threshold limit. A similar pattern has also been observed for the impact of energy innovation on carbon tax revenue. This study gives an indication that there might be a non-linear association between both these model parameters. The study outcomes have paved a way to design a policy framework for helping Swedish economy to attain the

[1] Corresponding author

objectives of Sustainable Development Goals, while paving the ways to achieve carbon neutrality.

Keywords: Carbon neutrality; Carbon tax; Energy innovation; Sustainable Development Goals; Sweden

1. Introduction

With rising emission levels across the globe and the need to meet the 2030 Sustainable Development Goals (SDGs), nations are devising strategies to achieve carbon neutrality. In this pursuit, the nations are striving to bring forth certain transformations in their economic growth trajectory, which is largely driven the fossil fuel-based solutions. While treading along this transformational path, the world has seen several policy instruments, which are targeted at achieving carbon neutrality. If these policy instruments are analyzed, then it can be understood that these instruments are largely driven by innovation. In advent of the SDGs, the role of innovation is getting realized more prominently, as realization of the SDG objectives is largely dependent on the proper implementation and diffusion of innovation. In view of this, the role of innovation might become significant not only in achieving carbon neutrality, but also to ensure a sustainable consumption and preservation of natural resources and to ensure energy security. This has led the nations to focus more on the energy innovations, among other forms of innovation. While evaluating the report on "*Mission Innovation Beyond 2020: Challenges and opportunities*" by Mission Innovation Secretariat, International Institute for Sustainable Development has stressed on the need of energy innovation in attaining the agenda 2030 (IISD, 2020). However, while stating the importance of energy innovation, the 6th policy brief report by the United Nations has discussed about the issue of investments in energy innovation (United Nations, 2018). In order to achieve the objectives of SDG 7, i.e., affordable and clean energy, it is necessary to mobilize the investments in pursuit of energy innovations, so that these solutions can be implemented and diffused both within and across the borders.

While the aspect of investments for energy innovations is discussed, the Nordic countries need a special mention. These countries have implemented a Pigouvian taxation mechanism, which can help in achieving carbon neutrality by internalizing the negative environmental externality exerted by the production processes, while boosting the energy innovation by means of the tax revenue. This mechanism is referred to as the carbon taxation, which is an economic signal that mandates emitters to incur monetary loss for adopting non-green practices and at the same time push them to adopt eco-friendly products and services. Apart from its deterrence motive, the tax revenues collected from such initiative are channelized to promote energy innovation (to reduce the carbon footprint in future), and in some cases, such revenue streams are directed towards building social safety nets, which is especially attracting attention of the policymakers in the developing markets (Mintz-Woo et al., 2020). However, it is often observed that the burden of carbon taxation is relatively less in comparison to investment in eco-friendly designs and practices. This severely impacts the sole objective of achieving carbon neutrality (Mintz-Woo et al., 2020). Hence, the taxation rules remain an important instrument, which decides whether organizations have sufficient incentive to move towards energy efficient practices. On the other hand, energy innovation practices at the country level undertaken from the revenue receipts of carbon tax may not benefit all sectors in the economy. Also, with countries moving towards energy efficient systems, the overall carbon tax receipts will come down reducing the revenue generation stream, which was earlier used for the benefit of the economy, either through promotion towards energy innovation or towards building social safety nets. While debating about the applicability of carbon tax, Booth and Whyte (2018) also point out the total loss of economic welfare owing to this Pigouvian taxation mechanism. Their discussion points towards a threshold limit of carbon tax regime, which points towards a fundamental policy debate: "*What should be the limit of carbon tax?*" Thus, the effectiveness of the carbon tax (below and above a certain threshold) may be debatable from the perspective of different economies (service dominated versus manufacturing dominated; developed versus developing) as well as the ability to promote energy innovation in relation to the carbon tax regime. This association might prove to be critical from the perspective of achieving carbon neutrality, and there lies the focus of the present study.

Based on this discussion, it becomes evident that the countries, which have implemented the carbon tax mechanism to achieve carbon neutrality, might require a policy-level reorientation, so that they can make certain progression towards devising the threshold level of carbon tax for promoting energy innovation. In this pursuit, the economy of Sweden might be chosen as a case to be discussed. There are certain reasons behind this choice. First, Sweden levies the highest carbon tax in the world which was implemented in 1991. The current carbon tax rate is approximately 126 USD per metric ton of CO2 and is primarily directed towards fossil fuels used in heating devices and motor fuels for transport (Jonsson et al., 2020). Hence, it serves as a benchmark purpose to understand the impact of carbon tax on the economy. Second, it is interesting to note that Sweden's GDP increased by 78% from 1990 to 2017 while domestic greenhouse gases emissions decreased by 26% (Schiebe, 2019) thus highlighting how Sweden managed to maintain economic growth despite the high environmental tax regime. Third, one third of the emissions are attributed to the transport sector in Sweden (Schiebe, 2019), which supports the argument, as how such Pigouvian tax scheme is targeted to few sectors, and therefore, the outcome of the same (such as energy innovation) could be restricted to certain sectors only. This means that as we move towards a situation where countries become greener, the revenue streams generated from carbon pricing would go down and may impact significantly important economic activities in a nation. Hence, by deriving important learnings for Sweden as the unit of analysis might act as a baseline policy-driven approach for the other countries, which have implemented the carbon tax mechanism.

In continuation of this discussion, the research objective of the present study can be laid down. The present study aims at understanding the dynamics between carbon tax revenue and energy innovation in Sweden over a period of 1990-2019. As the diffusion of energy innovation in Sweden has not yet reached its full potential, while they are considered as the pioneers in implementing carbon tax. While having a common objective of achieving carbon neutrality, these two policy instruments might be at a crossroads of tradeoff, which might deter further implementation of these instruments effectively. The intention of exploring the dynamics between carbon tax revenues and energy innovation is to capture the effectiveness of a) levying more carbon tax beyond a certain threshold, and b) energy innovation measures to different sectors in an economy and hence the relevance of relative carbon tax burden with green initiatives. Hence, a theoretical assumption can be made that there might be a possible non-linear relationship between carbon tax revenue and energy innovation, which might be driven by a threshold value. Understanding of this threshold would add more clarity for nations, as they move towards decarbonization, while maintaining economic growth, especially on what should be an appropriate carbon tax level for a certain type of economy. Findings from this exploration might help Sweden to devise an SDG-oriented policy realignment, which can have its direct implication towards SDG 7 (affordable and clean energy) and SDG 12 (sustainable production and consumption). Exploring this bilateral SDG-oriented policy realignment by discovering the possible threshold of carbon tax-energy innovation association is the policy-level contribution of the study. By far, literature has majorly focused on the regulatory (Aldy, 2020; Brooks and Keohane, 2020), trade (Nie et al., 2019), and technological (Popp, 2020) perspective of the association while designing the contextual policies, the present study has made an endeavor to made an attempt to conceptualize the possible threshold in the association. Apart from the study conducted by Lin and Li (2020), we have not come across any study, which has tried to capture this impact, and there lies the theoretical contribution of the study.

Now, while discussing the policy-level contribution of the study, it is also necessary to discuss about the methodological complementarity, as fulfillment of the research objective solely depends on this aspect. As it is hypothesized that the possible association between carbon tax revenue and energy innovation is non-linear, and the hypothesized association might have a possible threshold, it is necessary to capture the entire spectrum of both the policy parameters. This spectrum can be captured through decomposing the data into quantiles, and the dynamics between these two policy instruments can be discovered by analyzing the corresponding impact of one's quantile distribution on another. In this pursuit, the quantile-on-quantile regression (QQR) method introduced by Sim and Zhou (2015) has been applied, as this method allows to examine the inter-quantile dependence of carbon tax revenues and energy innovation. In comparison to quantile regression, the QQR method can regress the quantiles of the covariate with the dependent variable's quantiles, thus providing additional information of behavior of the relationship across quantiles. Application of this method complies with the policy-level focus of the study, and this methodological complementarity warrants analytical contribution of the study.

The remainder of the paper is as follows: Section 2 summarizes the key literature concerning energy innovation, carbon emissions and carbon tax and points out the research gap. Section 3 introduces the empirical framework and data. Here, in addition to the data description, we highlight the theoretical framework on which we base our research objectives and empirical model. Section 4 presents a detailed discussion on the results followed by standard robustness checks for our results. We conclude our paper by highlighting the research and policy implications of this study.

2. Literature review

Most of the world innovations take place in industrialized countries having an abundance of energy-intensive firms. Undoubtedly, economic prosperity is proportional to a country's energy production and consumption which make it more susceptible to environmental degradation. In line with the Environmental Kuznets Curve (EKC) hypothesis, environmental sensitivity is a phenomenon witnessed in countries after they have attained a certain level of industrial-led economic prosperity (for a detailed review, see Shahbaz and Sinha, 2019). At this juncture, the governments across the developed or developing nations have started taking serious measures against carbon emissions. The 2050 Low Carbon Roadmap reflects the ambitious goal of the European Union to reduce carbon emissions by 80-95% (European Commission, 2011). To valorize such a target, one of the effective policy-level regulatory mechanism is to design an effective carbon taxation system (Maron and Toder, 2014). Recent research has proved that imposing a carbon-tax system can curtail negative externalities and facilitate clean innovation (Acemoglu et al., 2016; Chen et al., 2020; Zameer et al., 2020).

2.1. The relationship between carbon emission and energy innovation

As research has hinted at a negative relationship between technological innovations and carbon emissions, climate policy-level researchers are focusing more on the impact of clean innovation on CO2 emission. Clean or "green innovations" emphasize energy efficiency (ratio of energy input to economic output)- an important metric to measure energy innovation of countries (Erodgan et al., 2020; Zafar et al., 2021). Demir et al. (2020) investigated the influence of domestic innovation on environmental degradation in Turkey from 1971-2013. They studied the relationship between innovation and CO2 emissions and proposed an inverted-U structure that depicts a rise in carbon emission during the initial stages of domestic innovation. However, after a certain level of innovation-led economic growth, a drastic drop has been observed in the CO2 emission level. Considering data on production-based energy efficiency and CO2 emissions (from 2005-2012) of BRICS countries, Santra (2017) concluded that innovative environment-related technologies reduce energy absorption and CO2 emissions. The empirical evidence provided by Ghisetti and Quatraro (2017) suggests that environmental innovations or green innovations positively affect the environmental efficiencies of a few Italian regions. Considering leading innovative countries and their economic growth and CO2 emissions for the period between 1990-2014, Tnani (2018) concluded that environmental taxes, high-tech exports, R & D expenditure, and innovation can help in reducing CO2 emissions.

It is to be noted that many research articles have reported mixed or different results in the relationship between innovation and CO2 emissions. After analyzing Malaysian data from 1971-2013, Yii and Geetha (2017) have found that in the short run, a negative relationship exists between technology innovation and CO2 emissions. However, the direction of such a relationship reverses in the long run. A study by Dauda et al. (2019) on eighteen developed and developing countries' innovation, growth and carbon emissions revealed that innovation boosts carbon emission reduction in G6 countries while carbon emission increases with innovation in MENA and BRIC countries. After considering a set of factors on a sample of 30 developing countries, Kapusuzoglu and Karan (2012) found that all types of causality (unidirectional, bidirectional and no causal relationships) exist in CO2 emission and energy consumption relationship. The absence or presence of a causal relationship and its direction are dependent on country-specific characteristics such as energy security position, the potential for industrialization, energy production capacities, economic growth level and the population of that country. Another line of research by Toda and Yamamoto (1995) and Yamada and Toda (1998) on Nordic countries revealed that a unidirectional causal relationship exists between renewable energy and CO2 emissions in Denmark and Finland. On the other hand, a bidirectional causality was observed in countries such as Sweden and Norway.

2.2. The relationship between carbon taxation and energy innovation

Carbon tax and carbon trading are two widely used governmental economic measures to curb carbon emissions. As it is difficult to set the carbon quota and distribute the same in the carbon market, many countries prefer a carbon taxation system. China has recently introduced such a system to energy-intensive industries (Tan and Lin, 2020). It is a well-accepted fact that after the imposition of carbon taxes on fossil fuel consumption levels, the prices of different energy types would vary, making a drastic change in energy demand (output). This would lead to an adjustment in the factors of production (input) and thus the substitution/complementation among energy types and factors of production would lead to a change in the energy efficiency index of a country. Moreover, carbon taxation has implications on induced energy innovations as there is an incentive to innovate to reduce the usage of more expensive fossil fuel and emit less carbon.

Using the computable general equilibrium model, Lin and Jia (2018) analyzed the impact of carbon tax policy on energy and suggested a higher tax rate for energy-intensive industries. According to Liang et al. (2007), carbon tax rates share a negative relationship with the macro-economic growth of a country but the tax income can be used to provide subsidy to production sectors to boost innovation. Studies show that price-based policy instruments (e.g., tax measures and tariffs) are most effective in fostering innovation in solar, wind and nuclear energy (Larsen et al., 2018; Veugelers, 2012). Though recent research by Loganathan et al. (2014) found an inverted U-shaped relationship between economic growth and CO2 emissions, the impact of a carbon tax on CO2 emission is ineffective due to the presence of a feedback effect. A study by Friedman et al. (2012) revealed the effectiveness of CO2 emissions in the short-run only, however, its effect subsides in the long run. On the other hand, in Norwegian countries, Bruvoll and Larsen (2004) claimed that carbon tax has a positive impact on environmental quality.

2.3. Research gap

Though most of the previous literature has examined the causal relationships between renewable energy, CO2 emission and economic growth, they have failed to consider technical innovations that aimed at increasing the energy efficiency of countries (Irandoust, 2016). The degree to which novel methods of energy generation and consumption impacts the macro-economic growth of a country in both the short and long run is undoubtedly a new area in energy research. Moreover, the effect of price-based policy instruments such as carbon taxation in such endogenous growth (or degrowth) fostered due to technological innovations, is worth considering as a research objective. The present paper also tries to find out whether any bi-directional relationship exists between energy innovation and carbon-taxation as a price-based policy regulation.

Apart from that, overview of literature also undermines the fact that there might be a tradeoff between the impacts of policy instruments, while the intended objectives of these policy instruments are analogous in nature. From the perspective of accomplishing carbon neutrality, existence of this tradeoff might be caused by a possible threshold in this association. This is another aspect of a policy level void, which has been ignored in the literature. The present study also aims to address this gap.

3. Empirical framework and data

The study has been carried out by considering the following steps: (a) investigating the order of integration, (b) investigating the presence of cointegration, and (c) estimation of long-run coefficients. In this pursuit, quantile autoregressive unit root test by Koenker and Xiao (2004), quantile cointegration test by Xiao (2009), and quantile-on-quantile regression (QQR) test by Sim and Zhou (2015) have been employed. Detailed descriptions of these tests are provided in Supplementary Materials 1.1 and 1.2.

3.1. Theoretical underpinning

While moving along the economic growth trajectory, the natural resources are depleted and environmental degradation takes place. In order to protect environmental quality and ensure energy security, a nation needs to embark on promoting energy innovation. Energy innovation can initiate energy transition in a nation, and this transition might result in renewable energy generation and bringing energy efficiency (World Energy Council, 2021). Based on the energy innovation, the issue of ambient air pollution can be reduced (Georgeson et al., 2016). Now, promoting energy innovation comes with certain financial implications, which needs to be considered without harming the prevailing economic growth trajectory. In this pursuit, the policymakers ponder upon introducing the carbon tax mechanism, the revenue generated from which is channelized towards promoting energy innovation. This financing mechanism will not only aim at reducing carbon emissions, but also will promote energy innovation for reducing carbon emissions. Therefore, it can be assumed that carbon tax revenue has a certain impact on the energy innovation.

On the other hand, while maintaining the carbon tax regime, it is also necessary to understand that the underlying sectoral transformation in the economy towards being service-oriented might reduce the carbon burden of the economy, while minimizing the utilization of energy innovation, as the service-oriented business processes will start internalizing the negative environmental externality exerted by means of the industrialization process. At the same time, unequal diffusion of energy innovation solutions might lead to continuance of the burden of carbon emissions from certain sectors. Owing to this phenomenon, carbon tax revenue earned by the government might show a disparity, which is attributable to the energy innovation.

From this discussion, it can be assumed that there might be a bidirectional association existing between carbon tax revenue and energy innovation, which is by and large ignored in the policy debate. While the impact of carbon tax revenue on energy innovation reflects the demand side of the story, the impact of energy innovation on carbon tax revenue might reflect the supply side considerations. Besides, the unequal distributive impacts of both the model parameters on each other give an indication that there might be an underlying threshold, which is possibly directing this association. In this study, this associative nature of these two policy parameters has been analyzed following a quantile-level disaggregated methodological approach.

In mathematical terms, this association can be expressed in terms of the *Feedback Hypothesis*, which is focused at analyzing the bidirectional association among model parameters. Following this, the association to be analyzed in this stud can be expressed as:

$$\mathrm{CTAX_t} = \mathrm{f_1(EI_t)} \tag{1}$$
$$\mathrm{EI_t} = \mathrm{f_2(CTAX_t)} \tag{2}$$

Here, CTAX is the carbon tax revenue, EI is the energy innovation, f_1 and f_2 are the respective functional forms of the associations, and t is the time frame of the study.

As the empirical model is based on a bivariate framework, it is quite obvious that the model will suffer from the endogeneity issue, and this issue might be arising out of omitted variable bias. In absence of other control variables in the model, it might be possible that the stochastic error term is correlated with the explanatory variable, which might cause the endogeneity issue. As the QQR approach does not allow the moderating impact of any third variable, the issue omitted variable bias persists in the model. However, in order to have a control over the issue, Xiao (2009) quantile cointegration model has been adopted for understanding the nature of cointegration among the variables (Cho et al., 2015). Presence of cointegration among the variables has ensured that the model is provisionally free from endogeneity issues.

3.2. Data

The present study utilizes the annual data for Sweden over a period of 1990-2019. Following Sinha et al. (2020 a, b, c), yearly frequency of the data has been converted into monthly frequency through quadratic match-sum procedure. Data for carbon tax revenue (in million USD) have been collected from the Carbon Pricing Dashboard (World Bank, 2019a), data for gross capital formation (current USD) have been collected from the World Development Indicators (World Bank, 2019b), data for gross value added by kind of economic activity have been collected from United Nations Statistics Division (UNSD, 2019), and data for final energy consumption by sector have been collected from International Energy Agency (IEA, 2019a).

In line with Chen et al. (2021), energy innovation has been measured by energy efficiency, and the process of measurement has been outlined in Supplementary Materials 1.3.

4. Discussion of results

4.1. Initial model diagnostics

The analysis is initiated with checking the model diagnostics for the applicability of long run estimation procedure. In this pursuit, (a) quantile autoregressive unit root test by Koenker and Xiao (2004) has been applied for scrutinizing the integration properties of model parameters, and (b) quantile cointegration test by Xiao (2009) for scrutinizing the cointegration properties of model parameters. The test outcomes reported in Supplementary Materials 2 and 3 divulge that (a) the model parameters are free from the unit root problem and are integrated to first order across all the quantiles, and (b) the model parameters are cointegrated. Based on the positive outcome of the initial model diagnostics, further analysis of the long run coefficients can be carried out.

4.2. QQR estimates

In pursuit of the estimation of long run coefficients, the study has employed the QQR approach of Sim and Zhou (2015), and the model estimates are plotted in the Figure 1. The figure depicts the slope of the regression line, represented by $\phi(\lambda, \tau)$. This slope discloses the influence of the τ^{th} quantile of energy innovation on the λ^{th} quantile of carbon tax revenue. This test outcome represents the dynamics of the association across various quantile ranges. The results show that at the lower quantiles of both the variables, the negative influence of energy innovation on the carbon tax revenue is the highest. At the low level of energy innovation, the negative impact gradually diminishes with rise in the quantiles of carbon tax revenue. Starting from the 0.40^{th} quantile, i.e., after arriving at a proximity of the median quantile, impact of energy innovation starts increasing across the quantile distribution of carbon tax revenue. However, it can be seen that the negative impact of energy innovation also diminishes towards its higher quantiles, if any particular quantile of carbon tax revenue till 0.65^{th} quantile is considered. Beyond this quantile, the negative impact of energy innovation starts increasing on carbon tax revenue towards its higher quantiles. This particular segment of the results gives an impression that the impact of energy innovation on carbon tax revenue reverses after the latter reaches a certain threshold limit. It might be possible that the government might not be benefitted by the firms facing lower and medium carbon tax in comparison with the firms facing higher carbon tax. This segment of the findings extends the finding of Sharma et al. (2021). This might give the policymakers a direction to realign their energy policy for targeting the firms in promoting energy innovation, as firms facing lower carbon tax might not be benefitted with the higher spectrum of innovation. Presently, the threshold mechanism is prevailing in Sweden only for taxing the energy use, and this mechanism pertain to the demand side of energy use (OECD, 2019). This aspect has been touched upon in the findings of Sinha (2017), while analyzing the inequality in renewable energy generation in the OECD countries. While this mechanism is in place, complementary supply side considerations of energy innovation is largely ignored, and this segment of the findings addresses that policy gap. This segment of the findings extends the findings of Fried (2018) by conceptualizing a possible threshold of carbon tax revenue for energy innovations to realize its desired potential.

Place for Figure 1

On the other hand, the impact of carbon tax revenue on energy innovation has been analyzed, and the results are reported in Figure 2. The outcomes provide certain insights, which might prove to be crucial from the policymaking perspective. When the carbon tax revenue is low (i.e., 0.05-0.10 quantiles), higher penetration of energy innovation (i.e., 0.70-0.95 quantiles) is desired. This might be driven by the fact that the initial low penetration of energy innovation might not be sufficient enough to reduce the carbon emissions, and therefore, in the incidence of low carbon emissions, low penetration of energy innovation might not be effective. Saying this, it is also surprising to note that between 0.30-0.55 quantiles of carbon tax revenue, its impact on energy innovation is largely negative. The carbon tax revenue in this segment possibly pertain to the manufacturing and transportation sector, which are still to achieve the full potential of energy innovation. According to the recent report published by IEA (2019b) refers to the growing problem of energy-related CO_2 emissions in the transportation sector, and as per the study by IRENA (2020), a possible reason behind this has been attributed to majorly the localization of the solutions. Owing to this phenomenon, this carbon tax revenue being generated out of these sectors are not enough to motivate the diffusion of energy innovations. However, retention of the 1997 agreement of Industrialvtalet aimed at having a control over the cost of carbon damage by means of energy innovation (Cruciani, 2016), and the impact of this enforcement can be seen at the higher quantiles of carbon tax revenue (0.60-0.95). In these quantiles, the impact of carbon tax revenue has been largely positive till the median quantiles of energy innovation. This traces back to the possibility of a threshold of energy innovation beyond a certain point of carbon tax revenue. The energy innovations rise till a certain level at the higher level of carbon tax revenue, but further diffusion of energy innovation might be discouraged by the prevailing carbon tax regime. Hence, on one hand, when carbon tax can be a motivator for the firms to initiate energy innovations, on the other hand, it might be possible that the burden of carbon tax might be less compared to the implementation cost of energy innovation. This might be a crucial point for the policymakers to intervene, as prevalence of this condition might impede the energy transition plan of the Swedish policymakers. This segment of the findings resonates the phenomenon found by Wang et al. (2019) for China, while Zafar et al. (2020) touched upon this issue for the OECD countries.

Place for Figure 2

4.3. Threshold analysis

By far, the association between these two policy instruments has been discussed from the perspective of achieving carbon neutrality. While discussing these associations, aspect of the possible presence of a threshold in these associations emerge. This aspect might prove to be critical from both theoretical and policymaking perspective. The scenario can be bifurcated into two sides, i.e., demand side and supply side. While considering the demand side aspect of the scenario, the impact of carbon tax revenue as a driver of energy innovation is analyzed. In keeping the model outcomes, it is evident that with the rise in carbon tax revenue, the financial mobilization towards the implementation and diffusion of energy innovations rises. However, after reaching a certain threshold, rise in the cost energy innovation might discourage the firms to adopt energy innovation, and they might prefer continuing paying carbon taxes. A graphical representation of this phenomenon in Figure 3 resembles the *Engel Curve*, where below the line AB, energy innovation is preferred over paying carbon tax, whereas above the line AB, energy innovation loses its preference against paying carbon tax. The point B on the curve designates the threshold level of cost of energy innovation, beyond which firms start losing incentives to invest in energy innovation. This threshold might be a concern for the policymakers, as rise in the energy innovation might create a predicament on the way to achieve the energy security, and thereby attaining the objectives of SDG 7. From the perspective of renewable energy solutions, this issue has been demonstrated in Indian context by Sinha and Shahbaz (2018) and Zafar et al. (2019) for the Asia and the Pacific countries.

Place for Figure 3

Following the discussion on demand side scenario, now the supply side considerations will be discussed. While considering the supply side aspect of the scenario, the impact of energy innovation on carbon tax revenue is analyzed. In line with the outcome of empirical analysis, it is evident that the negative impact of energy innovation diminishes with the rise in carbon tax revenue, and when carbon tax revenue reaches a certain level of threshold, the negative impact of energy innovation starts to rise. The firms with lower carbon tax revenue have less incentives to implement energy innovation solutions. However, given *Ceteris Paribus*, as soon as the carbon tax revenue crosses a certain threshold level, it gives an indication that the carbon footprint of the firms is rising, and as a consequence, the carbon tax revenue earned by the government from that firm is also rising. In such a scenario, a rational firm should implement the energy innovation solutions to reduce the further tax burden arising out of its own carbon footprint. A graphical representation of this particular scenario is represented in Figure 4, and the association resembles the inverted U-shaped *Kuznets Curve* (Kuznets, 1955). In the figure, the point A on the Y-axis denotes the threshold level of carbon tax revenue. The region to the left of the line BC categorizes the firms with preference of paying carbon tax, while the region to the right of the line BC categorizes the preference of implementing energy innovation. This gives a certain direction for the realigning the prevailing energy policies in Sweden. It might not be advisable for the policymakers to implement high-end energy innovation solutions for the firms, which have lower carbon tax revenue. Instead, the focus of the policymakers should be on the firms, which are characterized by higher carbon tax revenue. This also gives the policymakers an incentive to boost the research and development process for bringing down the cost of implementation for energy innovation solutions. This might help Swedish economy to accomplish the objectives of SDG 7.

Place for Figure 4

In short, both the demand and supply side perspectives of the association between carbon tax revenue and energy innovation divulge that the nature of the association is nonlinear, with certain thresholds. While the demand side scenario resembles the Engel Curve, the supply side scenario resembles the Kuznets Curve. From theoretical perspective, these two associations can be significant for achieving carbon neutrality. While treading along the developmental trajectory, it might be possible that its policy instruments in action might create a tradeoff situation, in spite of having a common policy objective. While focusing on the sole policy objective, many a times the policy makers undermine this aspect, which might turn out to be potential deterrent to implement these policies. Discovery of these possible thresholds gives a clear indication regarding the presence of a possible tradeoff between these policy instruments. If both of these curvilinear associations are analyzed, then the thresholds of these associations can designate the points, where policy intervention might be necessary. Based on the ulterior policy objective of the nation, the policy interventions might be introduced for accelerating or decelerating the emergence of these thresholds.

4.4. Robustness check

For analyzing the robustness of QQR analysis, quantile regression approach is employed, and the distribution of slope coefficients for both the associations are depicted in Figure 3 and 4. The outcomes divulge the coefficients reveal just about comparable nature of movement across the quantiles. While the scales of coefficients vary in comparative terms, steering connotation among model parameters demonstrate robustness of the QQR outcomes. As quantile regression estimates are decomposed by QQR approach, therefore, slope estimates of quantile regression appropriately verify the robustness of the QQR approach.

Place for Figure 5
Place for Figure 6

5. Conclusions and implications

The present study looked into the dynamics between carbon tax revenue and energy innovation for Sweden over 1990-2019. In doing so, we have adopted an advanced quantile modeling approach, based on the QQR approach devised by Sim and Zhou (2015). The results obtained from the study give certain directions for policymaking, as well as give a direction for empirical research.

5.1. Theoretical implications and caveats

Decarbonization process in Sweden is catalyzed by the introduction of carbon tax mechanism, and this mechanism was supposed to bring down the CO_2 emissions. The revenue generated out of this tax collection is channelized towards promoting energy innovation. However, it might be possible that the energy innovation measures might prove to be ineffective in the event that the carbon tax burden is lower than the implementation cost for energy innovation. Moreover, all the sectors are not able to enjoy the benefits of energy innovation, and as a result, policymakers are unable to experience the potential impact of energy innovation on carbon tax revenue, and vice versa. The impact has been found to reverse beyond a certain threshold. This phenomenon gives an indication that possibly the association between these two parameters is non-linear in nature, and to be specific, the association might take a U-shaped form. This form of the association has not been analyzed in any context, and discovery of this curvilinear form might be a contribution to the literature, based on which an entire strand of empirical literature can be built. Discovery of this threshold can probably give direction to the empirical research in pursuit of decarbonization.

However, while stating these theoretical implications, it is also necessary to remember that this particular association has been analyzed following a bivariate framework, and therefore, there is a possibility that this association might suffer from endogeneity issues. Hence, while carrying out the analysis for finding the possible threshold of these associations, additional policy instruments might be added, so as to explain this association in a better way. Besides, inclusion of additional parameters might also solve the problem of omitted variable bias. The theoretical implications are drawn from this study assuming these caveats, and the findings of this study can be used as a baseline approach to analyze this association further in diverse contexts. In the course of future studies, these caveats can be addressed, so that more refined insights can be garnered.

5.2. Policy implications and caveats

On the policymaking front, the government needs to assess the status of diffusion of energy innovation across the sectors in Sweden. In case any sector is found to be deprived of the energy innovation, then a possible diffusion of the solutions should be carried out. It might be possible that the growth trajectory of the specific firms might rule out the possibilities of the energy innovation implementation, and those firms should be avoided for the diffusion of solutions. As the role of the policymakers is not to earn the revenue, but to ensure energy security and making the energy solutions affordable by means of the carbon tax mechanism, hence the policymakers need to utilize the carbon tax revenue for streamlining the clean energy demand and respective implementation of solutions (Sinha et al., 2018, 2020d). A possible solution might be the decentralization of the energy innovation solutions, so that access to the solutions can be independent of the locations. In this way, the transportation sector will be most benefitted. On the other hand, the policymakers need to bring certain sectoral transformation in the economy, so that economic growth trajectory in Sweden can be more clean energy-based service-oriented. In this way, the economic growth trajectory will be able to internalize the negative environmental externalities, without creating demand pressure on the energy innovation solutions. Thus, policymakers will be able to advance the Swedish economy towards attaining the objectives of SDG 7, i.e., affordable and clean energy, while bringing forth sustenance in their resource consumption pattern by attaining the objectives of SDG 12, i.e., sustainable consumption.

While carrying out these policy interventions, the policymakers need to understand the fact that these two mechanisms can act as substitutes beyond a threshold limit, and therefore, these two policy instruments need to be utilized carefully. Although both of these policy instruments have a common policy objective, the cost aspects of implementation can bring them at crossroads, where the tradeoff between the policy instruments will be visible (Balsalobre-Lorente et al., 2021; Sinha et al., 2021). In such a scenario, the role of threshold might turn out to be critical, as the tradeoff scenario might undergo a change beyond this point. In order to sustain the policy framework concerning SDG 7 and SDG 12, it is necessary that a proper balance between these two policy instruments is maintained. In the course of policy implementation, the policymakers need to ponder upon the fact that the sole objective of Swedish economy is decarbonization, and carbon tax might be replaced completely by energy innovation in future. Hence, the firms should be motivated towards adopting energy innovation solutions, and in that pursuit, the availability of credit should be made easy, so that the revenue stream of the firms can remain intact during the transformation phase. The main motivation behind this initiative is that the Pigouvian taxation should not act as a substitute for the implementation of energy innovation mechanism, as this might create a predicament on the way to accomplishing the objectives of SDG 13 in the long run.

There are certain caveats and assumptions, which build foundations of this policy framework. First, the policymakers should take stringent measures to reduce the depletion of natural resources and take progressive measures to reduce the consumption of fossil fuel-based energy. This can be achieved by making the laws for environmental protection more stringent and imposing substitution policies on the import of fossil fuels (Sinha, 2015). Second, the surplus labors from the traditional fossil fuel energy generation sector should be absorbed in the renewable energy generation sector, and to accomplish this, policymakers need to introduce vocational training initiatives. This move is essential for maintaining the social order, which could have otherwise been disturbed by means of the unemployment created in the former sector. Third, in order to spread the flairs of innovation at the grassroots level, the policymakers need to bring forth certain amendments in the educational curriculums and high school and graduate levels. This initiative will be focused at making the future generation of labor force more ecologically aware and sensitive.

5.3. Limitations and projections

While saying this, it is also needed to remember that the policy framework suggested in this study suffers from the limitations of omitted variable bias, as the study has been carried out following a bivariate empirical framework. Owing to this limitation, the possibility of endogeneity issues in the empirical model cannot be ruled out, and therefore, the policy suggestions recommended in the study need to be considered with caution. This can also be attributed to the methodological adaptation of the study, i.e., the QQR approach. Consideration of external control variables could have brought forth additional insights to the study, and that could have enriched the empirical contribution and the recommended policy framework. Saying this, it should also be noted that the recommended policy framework might provide with an idea about the possible policy directions to be considered in the Nordic countries, and from that perspective, this study adds value to the literature by bringing forth this policy benchmark. Further research on this context can be carried out by (a) considering the U-shaped association between carbon tax revenue and energy innovation, and (b) considering control variables within QQR framework. In methodological terms, future study on this aspect might be carried out by considering the nonlinear association between the variables through nonlinear autoregressive distributed lag framework or through threshold regression.

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