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Synergizing Financial Innovation and Green Technology for Carbon Emission Reduction in Financially Developed Economies

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Abstract
Technological advancements have long been recognized as drivers of economic prosperity over the long term. However, the impacts of certain technologies, particularly financial and environmental innovations, on the environment remain unclear. This study aims to explore the influence of non-linear financial innovation and green innovation on emission levels. To achieve the objective, the study utilized data from 1990-2022 of top 20 financially developed economies and employed the novel Method of Moments Quantile Regression. The findings reveal the existence of the Financial Innovation-Environmental Kuznets Curve hypothesis. The green innovation arises as a positive factor in declining emissions. The implications are quite convincing on the argument that highly financially developed economies should take certain additional steps to reap the full benefit from financial innovation. The initiation of weather derivatives will help to manage risks related to weather conditions, causing higher emissions. The launching of environment-friendly financial innovation, particularly for economies under the 70th quantile, will provide them with multiple benefits. Further, establishing green banks and green investment funds can play a prominent role in environmental sustainability.

Keywords: *Financial Innovation, Green innovation, Economic Globalization, MMQR, EKC*

JEL Classification: *Q55, Q54, O32*

1. Introduction

Climate change is a substantial global challenge in the twenty-first century, causing various environmental problems worldwide (Ali et al., 2022; Chen et al., 2023; Obobisa et al., 2022). It poses threats to the ecosystem, development, and sustainability (Raihan et al., 2022). Greenhouse gas (GHG) emissions, particularly CO2, are the primary drivers of global warming and climate change, posing the most substantial risks to the existence of life on Earth (Bui, 2020; Rahman et al., 2022). The deleterious effects of CO2 on human health and the environment are becoming more widely acknowledged, leading policymakers and scholars to address the pressing necessity for environmental preservation (Ibrahim & Vo, 2021). Hence, the international community has officially approved crucial agreements, such as the Paris Agreement, and has started developing plans to shift towards carbon neutrality and decrease the impacts of climate change (Jiang et al., 2021; Li et al., 2022). Therefore, to accomplish the objectives, economies need to identify the elements that have the potential to decrease carbon emissions (CO2) and establish a strategic plan for creating a sustainable environment.

The resolution of many contemporary environmental concerns necessitates innovation (Aldieri et al., 2019; Ekins, 2010). Both technological and financial innovation can be employed to advance sustainability in different businesses (Mongo et al., 2021). The environmental performance can be enhanced, to some extent, by the advancement and utilization of green innovation (Gpat) (Robert, 2000). To achieve a significant change in perspective, it is necessary to separate economic progress from environmental problems, particularly the deterioration of the environment, by using Gpat (Altenburg & Pegels, 2017). The environmental technology business has been widely acknowledged for its contribution to sustainable economic growth and environmental conservation (Ashford, 1993).

Gpat has played a crucial role in boosting productivity. Environmental technologies refer to the Tools, techniques, procedures, and delivery networks used in production to restrict or lessen the harmful environmental effects of goods or services (Klassen & Whybark, 1999). The development of renewable energy source turbines for power generation has experienced a significant increase in recent times due to technological advancements. Electric vehicles are gaining popularity due to low CO2 in comparison to gas-powered vehicles (Saudi et al., 2019; Wang & Luo, 2020; Zhang et al., 2020). Vertical farming, an agricultural invention, allows for the cultivation of crops with much-reduced amounts of land and water.

In addition, innovators are developing waste recycling methods that effectively mitigate the contamination of our seas and other natural ecosystems. In the past, it has been customary to prioritize technological solutions that capture and control pollutants at the source, before they are released into the environment, as a means of environmental improvement. Environmental technology commonly refers to the field of pollution control. While environmentalists have primarily focused on pollution control technology, recent research suggests that there should be more focus on prevention, reducing the source, or using clean technology to limit the initial generation of pollution. This approach aims to reduce the amount of pollution produced in the first place, as advocated by the US Environmental Protection Agency (1989) and (Freeman et al., 1992). Therefore, the utilization of these technologies leads to more efficient extraction and utilization of resources, lower presence of hazardous components in commodities, and a decrease in environmental degradation. Gpat solutions offer a means to achieve persistent environmental sustainability(ES) across various societal domains, such as industry, finance, and daily existence (Sharif et al., 2023).

To finance environmental initiatives, financial innovation (FIN) has been conceptualized as a tool. FIN includes the development of novel financial instruments that facilitate the management of financial risk, the transfer of risk, and the management of credit and liquidity. According to (Miller, 1986), FIN refers to new types of derivatives, products that allocate risk, funds that are linked to exchanges, and stock alternatives that can be deducted from taxes. These components are necessary to fulfill the budgetary requirements of a nation's innovation programs (Silber, 1983). FIN occurs through Innovation in product development and processes, which are influenced by the economic systems of nations. Although the primary goal of innovation activities is to mitigate climate change, it is anticipated that the financialization of these efforts would also necessitate innovation. The project's level of risk requires the adoption of this neo-financialization approach. FIN can have an indirect effect on environmental deterioration (Chishti & Sinha, 2022).

Ever since the pollution trading market was introduced, there has been a belief that FIN may be used to provide funding for environmental activities. (Allen, 2012) has shown that financing innovation has significantly contributed to supporting the implementation of the Clean Water Act of 1972 in the United States. This has been achieved through the introduction of debt swaps, state revolving funding, and individually transferable fishing licenses. (Delimatsis, 2009) conducted a study that provides insight into the sale of green energy certificates in the secondary market and its significant impact on the promotion of renewable energy solutions. Due to FIN, many developed countries reduced their dependence on fossil fuels. Carbon financing is a leading financial strategy that is used as a tool for fighting against environmental deterioration (Chishti & Sinha, 2022). Moreover, (Chien et al., 2021) revealed that in Asian countries, environmental quality is improved through FIN.

Following the introduction section of the study, the second part of the study provides literature reviews. The third part introduces the model, methodology, and dataset used in the study. The fourth part includes the empirical findings obtained. The study concludes in the last part, offering recommendations for potential investors and policymakers, as well as presenting explanations regarding the future direction of research. In addition, economic globalization has significantly amplified production and trading endeavors, resulting in a considerable rise in energy consumption, which consequently led to environmental pollution (Erdoğan et al., 2020). To increase the relevance of the concept of CO2 with globalization, it is necessary to acknowledge that numerous products are not consumed in the countries where they are manufactured.

The discussion of globalization's impact on the environment focuses on three main aspects: scale, composition, and technology. As globalization progresses, there will be a corresponding increase in energy consumption and emission levels, driven by the growth in economic activity. The composition effect of globalization has a significant economic effect of structural changes. Shifting towards a knowledge-based

service-oriented economy reduces environmental problems. Trade openness and capital inflow have a favorable impact on environmental quality by facilitating the importation of environmentally friendly technologies from other countries (Danish et al., 2018; Zhang et al., 2017). Lemos & Agrawal (2006) argue that globalization amplifies human demand by connecting global markets, resulting in escalated resource use, depletion, and waste generation.

This study provides new insights into the role of green innovation (Gpat) contributing to environmental deterioration. It aims to assist in the creation of policies related to environmental technologies and environmental deterioration. The primary aim of the study is to elucidate the impact of Gpat on CO2 of the top 20 economically advanced countries. Moreover, the FIN-Environmental Kuznets Curve (EKC) is examined. The current study uses the novel MMQR method, which considers the non-linearity and Non-symmetrical arrangement of the data. IV) To use data of the top 20 financially developed countries that are pioneers in financing the fight against climate change to meet the 2030 goals. The primary rationale for choosing these nations is that the 20 financially developed countries possess the necessary resources to advance technology. However, it is important to note that financial development frequently manifests a dualistic character with regard to ES. For example, financial stability based on banking contributes to the amplification of carbon emissions, while financial development based on the stock market aids in the reduction of carbon emissions or the enhancement of SDG. Examining the relationship between FIN and ES will shed light on whether or not the former two factors contribute to the improvement of environmental conditions in economically stable nations.

Our study makes two contributions to the existing literature. First it explores the role of financial innovation and green innovation on CO2 of the top 20 highly financially developed economies that have not been previously explored. Identifying the relationship for the top financially developed economies enables policymakers to formulate environmental protection measures that are more pragmatic and accurate. Furthermore, empirical research on the nations with the highest levels of FD has not been explored earlier. 2nd to the best of our knowledge, this is the first study which explored the nonlinear impact of FIN (FIN2) on the CO2. An important concern arises when considering the correlation between the ability of countries with well-developed financial sectors and substantial technology expenditures and their CO2 emissions.

This study aims to address issues over the allocation of financial resources by industrialized nations towards development goals outlined in the Paris Agreement and the SDG of the 2030 Agenda. The question of whether FIN and Gpat contribute to ES in economically stable countries remains unresolved to the satisfaction of inquisitive individuals. Analyzing the synergistic impact of green initiatives and financial stability on ES in economically prosperous nations would offer policymakers valuable insights to develop practical solutions for addressing environmental concerns and achieving sustainable economic growth. In other words, the results of this research will enhance our comprehension of the interaction between FIN, Gpat, and the environment. Additionally, it will provide stakeholders and policymakers with vital insights to grasp the intricacies of SDG.

2. Literature Review

Studies understanding factors affecting carbon emissions have been conducted by many scholars across different regions and using various methodologies. Of many factors, globalization, technological innovation, FIN, and economic growth are the focused environmental quality determinants in this study. Hence, understanding how these factors affect carbon emissions should be examined thoroughly. The following subsection covers the selected literature review on carbon emissions and the focused key determinant in the panel countries' setting.

2.1 Globalization and Carbon Emissions

International trade is one of the channels through which globalization affects environmental quality. However, the evidence on the issue remains inconclusive. Some studies demonstrate that globalization has a detrimental impact on environmental quality by increasing carbon emissions. For example, Sultana et al. (2023) investigated the sample of N-11 countries. By utilizing pooled, fixed, and random effects, the study confirms the validity of EKC hypothesis. The study demonstrates that globalization deteriorates the environment by increasing emissions. Khan et al. (2022) provided the same conclusion for Asian countries. However, the main

channel through which globalization increases emissions is via the energy consumption channel. That is, globalization tends to increase non-renewable energy consumption, which consequently increases carbon emissions.

In the case of European countries, Vlahinić Lenz & Fajdetić (2021) investigate the impact of globalization on GHG emissions in 26 European Union countries from 2000 – 2018. Based on dynamic panel data regression, the study demonstrates that globalization has a significant and positive impact on greenhouse gas emissions. Furthermore, the study also demonstrates that globalization and greenhouse gas emissions are bi-directionally correlated. However, some other studies demonstrate that the relationship between globalization and carbon emissions is non-linear. That is, globalization initially decreases carbon emissions, but it rebounds to be detrimental after passing a particular threshold level, which mimics a U-shape pattern. For example, Adeleye et al., (2023) investigate the impact of globalization on carbon emissions in the case of South Asia. Based on the different techniques, the study demonstrates that globalization and carbon emissions form a U-shape relationship. Contrary, the Liu et al., 2020 study reveals that globalization has an inverted U-shape relationship with CO2.

Finally, amid the mixed findings, Asliyana (2023) also investigated the impact of globalization on carbon emissions in the selected eight highly developed economies during 2017 – 2021. The selected countries are the USA, the UK, Italy, Japan, Germany, Canada, and Russia. The study demonstrates that globalization has a significant and negative impact on carbon emissions, which indicates that globalization reduces carbon emissions.

2.2 Green Patents and Carbon Emissions

Existing research on the relationship between green patents and carbon emissions reports inconsistent results. Some studies demonstrate that green patents have a positive impact on environmental quality. For example, Fakher & Ahmed (2023) investigate the impact of technological innovation on environmental quality by taking account of the role of financial development. The study is conducted for 25 OECD countries from 2000 – 2019. Using two steps system Generalized Method of Moment (GMM), the study demonstrates that technological innovation significantly and positively affects environmental quality by reducing the environmental vulnerability index in the sample countries.

Li et al. (2023) also demonstrate the ability of patents in reducing carbon emissions. (Li et al., 2023) investigated the impact of green innovation on carbon emissions in the case of 30 provinces in China for 2005 – 2020. The study is conducted specifically in the construction sector. The study features a model with threshold and mediating variables. The threshold variable is environmental regulation intensity, which is proxied using construction GDP over energy consumption, while the mediating variable is the log of the share of construction GDP of energy consumption. Using Two-way fixed effect panel regression, the study demonstrates green innovation has a significant impact in reducing carbon emissions in the region. Furthermore, the study demonstrates that environmental regulation can moderate the magnitude impact of green innovation on carbon emissions. On the contrary, Du et al., (2019) results revealed that green patents have no significant impact on carbon emissions. The authors investigated the impact of green technology innovation on carbon emissions in the case of 71 economies, covering both high-income and middle-income countries, over the period 1996 – 2012. The study implements panel regression with a fixed effect model and demonstrates that green technology has no significant impact on reducing carbon emissions for lower-income countries, but the impact is significant for higher-income countries. Furthermore, the study also demonstrates that the relationship between economic growth and carbon emissions follows an inverted U-shape.

Tan & Cao, (2023) investigate the impact of green technology innovation on carbon emissions in G7 and BRICS countries over the period of 1990 – 2019. The key independent variable in the study is green innovation, which is approximated by two variables: (1) green technological development, which is proxied using the number of patents of green international cooperation technology, and (2) green technology diffusion, which is proxied using patent counts of green technology diffusion. The random and fixed effect panel results showed that green technology development and green technology diffusion are both statistically significant and positive in affecting carbon emissions and carbon intensity, which indicates their ineffectiveness in improving environmental quality. However, on the contrary, the interaction of the two green proxies is statistically

significant and negative in affecting carbon emission and carbon intensity, both in the full sample, G7 sample, and BRICS sample countries.

Yu et al. (2022) also reported the similar findings by investigating the impact of innovation on carbon emissions in the case of 52 countries for 1990 – 2014. This study features the role of financial development as a threshold effect between technology innovation and carbon emissions. Thus, the 52 sample countries are classified into low financial development (FD) countries, and high FD countries. Using the dynamic panel threshold model as the primary method of estimation, the study demonstrates that, when innovation is proxied using patent applications, innovation has a statistically significant and positive impact on carbon emissions in highly financially developed countries when financial development is measured by private sector credit.

2.3 Economic Growth and Carbon Emissions

Many studies have investigated the relationship between economic growth and carbon emissions in various settings. Of the selected studies, the findings are concentrated into two polars. The first polar shows that economic growth has a detrimental impact on carbon emissions. For example, Alaganthiran & Anaba, (2022) investigate the effects of economic growth on carbon emissions in the case of 20 Sub-Saharan African (SSE) countries for 2000 – 2020. The finding implies that higher economic growth tends to reduce environmental quality. This finding is also similar to the study from Osadume & University,(2021) that investigates a similar relationship in the case of six countries in West Africa from 1980 – 2019. Furthermore, a negative impact on economic growth is also found in European countries. For example, Sisodia et al. (2023) examine the relationship between economic growth and environmental quality in 24 European Union member countries over the period of 2000 – 2020. Based on the estimation, the study demonstrates that economic growth tends to increase carbon emissions in the short run through the channel of energy consumption. Furthermore, the study also shows that economic growth also has a significant and positive impact on carbon emissions in the long run in the region. Moreover, it is also shown that a long-run relationship is formed between economic growth, energy consumption, renewable energy consumption, and carbon emissions in the long run.

Although most studies demonstrate the negative impact of economic growth on carbon emissions, some other studies argue that the relationship between them is non-linear or confirms the EKC hypothesis. For example, Niyonzima et al. (2022) investigate the relationship between economic growth and carbon emission in ten selected countries over the period of 2010 – 2019. The countries include the United States, the UK, Germany, Canada, China, Egypt, Nigeria, South Africa, Kenya, Ethiopia, and Rwanda. The study estimates the model using the error correction model (ECM) and demonstrates that the short-run relationship between economic growth and carbon emission is negative, meaning that the rise in carbon emission tends to reduce economic growth in the short run. However, in the long run, the study demonstrates that the relationship between economic growth and carbon emissions is positive, meaning that the rise in carbon emissions tends to increase economic growth.

Furthermore, Jardón et al. (2017) also demonstrate the confirmation of the EKC hypothesis in their findings. That is, Jardón et al. (2017) investigated the impact of economic growth on carbon emissions in the case of 20 countries of Latin America and the Caribbean during the period between 1971 – 2011. The study implements two-generation panel regressions. The second generation assumes cross-dependence while the first generation does not. In other words, the EKC hypothesis is confirmed under the first generation. Similarly, the finding of the EKC hypothesis is also found in Sultana et al., (2023) who investigate the relationship in the case of 11 sample countries. The sample consists of Bangladesh, Egypt, Indonesia, Iran, Mexico, Nigeria, Pakistan, Philippines, South Korea, Turkey, and Vietnam, which are classified as the Next 11 countries (N-11), for over the period of 1990 – 2019. The study demonstrates that per capita GDP increases carbon emissions, but its squared form reduces the emissions in the long run, which confirms the EKC hypothesis.

2.4 Financial Innovation and Carbon Emissions

FIN can affect carbon emissions through credit or stock market channels. Findings related to the impact of financial innovation on carbon emissions are also mixed. For example, some findings demonstrate that financial innovation tends to reduce carbon emissions. This finding is confirmed by Tekbaş (2023) who investigated the impact of FIN on environmental quality. The study is conducted for 14 OECD countries as a

sample with the period between 2009 and 2019. The model is estimated using FMOLS and demonstrates that financial innovation has a statistically significant and negative impact on carbon emissions, which means that the rise of FIN tends to reduce carbon emissions. Furthermore, the Dumitrescu-Hurlin causality test also demonstrates that there is a unidirectional causality running from FIN to carbon emissions. In the case of UAE and Saudi Arabia, the reducing impact of FIN on carbon emissions is also confirmed. Belgacem et al. (2023) investigate the impact of financial innovation on environmental quality amid the presence of renewable energy consumption. The study is conducted for the UAE and Saudi Arabia as the sample countries over the period of 2010 – 2022. The estimation is conducted using FMOLS and DOLS regression where the study demonstrates that FIN significantly and negatively affects CO2 emissions in the UAE and Saudi Arabia. This finding implies that financial innovation and renewable energy contributes to the reduction of carbon emissions.

The positive impact of FIN on environmental quality is also confirmed by Ren et al. (2023) who investigated the impact of financial development on carbon emissions in 30 provinces in China. The study implements the STIRPAT model and demonstrates that financial development significantly reduces carbon emissions in the long term. Furthermore, the study also demonstrates that the impact of financial development on carbon emissions is stronger poverty levels are lower. Furthermore, although financial development may reduce carbon emissions at the regional level, it can still increase the emissions in neighboring countries through the spatial spillover effect. Similar to Ren et al. (2023), Li (2023) and Yu (2023) also utilize provincial-level data in China over the period of 2005 – 2019 and demonstrate that financial innovation in the form of financial digitalization can help in reducing carbon emissions in the country. However, on the contrary, a detrimental impact of FIN on economic growth is also found in the study (Fakher & Ahmed, 2023). Specifically, Fakher & Ahmed (2023) investigate the impact of technological innovation on environmental quality by taking account of the role of financial development. The study is conducted for 25 OECD countries over the period of 2000 – 2019. Using two steps system Generalized Method of Moment (GMM), the study generates six different models and demonstrates that financial development is statistically significant and negative in affecting environmental quality in the sample countries. That is, higher financial development corresponds to higher carbon emissions. Furthermore, the study also demonstrates that financial development could moderate the impact of technological innovation on environmental quality.

In light of above mentioned studies, despite the growing body of literature examining the environmental implications of financial development and innovation, several important gaps remain unaddressed. Most existing studies have focused on broad samples of developed and developing countries or have concentrated on emerging economies, often overlooking the specific dynamics of the world's most financially advanced nations. The environmental impact of financial and green innovation within the top 20 highly financially developed economies has not yet been thoroughly investigated. In addition, while financial innovation has been acknowledged as a potential driver of environmental change, its nonlinear effects on CO_2 emissions remain insufficiently explored. Specifically, the hypothesized inverted U-shaped relationship FIN-EKC has not been empirically tested in the context of financial innovation, particularly in financially developed countries. To the best of our knowledge, financial innovation (linear and nonlinear), economic globalization, green patent and economic growth within a single empirical framework have not previously explored. This study addresses these gaps by focusing exclusively on the top 20 highly financially developed economies and examining both linear and nonlinear impacts of financial innovation alongside other critical environmental determinants, thereby contributing new insights to the financial-environmental research nexus.

3. Methodology and Model

3.1 Theoretical Framework

Since the pioneering study of Grossman and Krueger (1991), researchers have agreed that rapid economic expansion is the primary cause of ecological damage. Through the effects of scale, composition, and technology, economic growth can have an impact on environmental quality. According to Grossman and Krueger (1991), nations utilise their rising incomes to invest in environmentally friendly technologies. As a result, technical advancements can help to lessen ecological pollution. Nevertheless, as technology advances, output may increase (scale effect), hastening environmental deterioration in the process. These theoretical

justifications allow for the identification of various connections between environmental development and technological advancement.

One of the channels through which globalization can affect carbon emissions is via international trade, that is, export and import. The more interconnected the countries are, the more countries can enjoy greater market size or new market destinations for their export. With higher export opportunities, domestic firms will produce more goods for export commodities which inevitably forces them to increase their energy consumption. Furthermore, greater energy consumption can contribute to the rise of carbon emissions. Thus, one of the most relevant theories related to the relationship between globalization and carbon emissions is the international trade theory, such as the Heckscher-Ohlin theory (Dogan et al., 2020; Rogoff, 2005). Copeland, (2021) explains that Heckscher-Ohlin theories suggest that the main impact of trade on the environment is pollution. Therefore, reallocation of production within industry is necessary to capture the main drivers of environmental change. Higher globalization is also indicated by the rise in joint projects between countries through investment. When one country invests in another country, it will invite more infrastructure developments in the host country that also require more energy consumption, especially non-renewable energy consumption. Subsequently, higher energy consumption drives carbon emissions and reduces environmental quality.

Foray & Grübler (1996) demonstrate the paradox of technological development where technology and environment have a dual nature. Specifically, first, the theory explains that technology has an unprecedented impact on the environment in the form of rising pollution which occurs through the energy consumption channel. Second, however, technology can remedy the environment from degradation. Hence, encouraging the development of patents is considered one of the long-term solutions to improve environmental quality, or reducing carbon emissions. Green patents are recently known as one technological maneuver to protect environment. Green patents show the degree of technological progress that the country has been implementing to improve its environmental quality. Theoretically, innovation is a product of accumulated knowledge to effectively tackle the current issues. Hence, when new environmental innovation is introduced, the new technology should be able to improve the environmental quality at least in the short run. Thus, with better environmental quality, carbon emissions should be reduced.

FIN may affect carbon emissions through the innovation of financial instruments. Biernacki (2021) explains that innovation in financial markets is mostly related to the development of financial instruments that are traded through international financial markets. One of the recent financial instruments that is closely related to the environment is green bonds. The innovation of green bonds has attracted the attention of investors by offering new opportunities for them to invest in environmentally-friendly projects. Through the purchase of high stocks of green bonds, more funds are allocated to support more environmentally friendly projects. Furthermore, with more green projects, carbon emissions can be reduced because the project is now prioritizing more clean energy consumption. A similar mechanism also holds in banking. Recent innovations known as green loans also aim to channel funds to firms that actively participate in green projects. If banks prioritize expanding green loans on their loan portfolio, more green projects can be covered, and more reduction of carbon emissions can be achieved. However, the efficacy of FIN in reducing carbon emissions is conditional on the degree of financial inclusion and awareness of the country towards the importance of the environment.

The theoretical justification for including the quadratic term of FIN in analyzing its impact on CO_2 emissions lies in the expectation of a non-linear relationship, inspired by frameworks like the Environmental Kuznets Curve (EKC). Financial innovation can have both positive and negative environmental implications, depending on its stage of development. In the early phases, financial innovation tends to facilitate increased industrial activities by improving access to credit, investment, and financial products. This "scale effect" leads to higher production and consumption, often powered by fossil fuels, thereby increasing CO_2 emissions. However, as financial systems mature, innovation begins to support the "technique effect" where more advanced tools i.e.,

such as green bonds, carbon trading mechanisms, and ESG-focused investments, promote the adoption of cleaner technologies and more sustainable business practices. This evolution implies a turning point: FIN initially contributes to environmental degradation, but beyond a certain threshold, it begins to reduce emissions by enabling efficient resource allocation, supporting green R&D, and aligning financial incentives with environmental goals. The quadratic term in the model thus captures this inverted U-shaped relationship.

Based on these justifications, the study investigated the influence of linear and non-linear financial innovation on CO2 of the top 20 highly financially developed economies. To achieve the objective, the analysis uses yearly data from 1990 to 2022.

3.2 Empirical Model

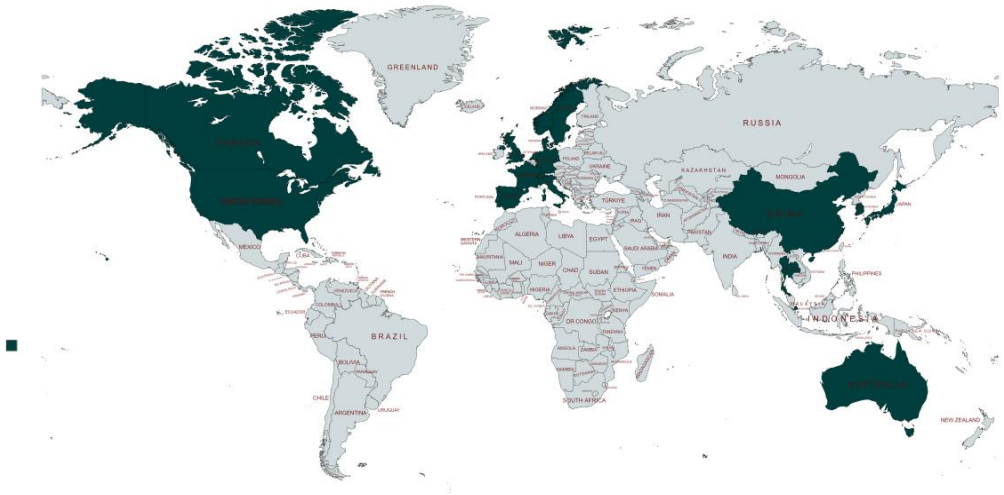
Our dataset is in panel form, which is constructed from 20 highly developed economies for 1990 – 2022. Table 1 below summarizes the variables used in our study. However, the geographic location of the sample countries is shown in Figure 1.

Table 1: Variables Summary

Symbol	Variable	Proxy	Data Source
CO2	Environmental degradation	CO2 emissions	World Bank
FIN	Financial innovation	Broad money	OECD database
ECG	Economic globalization	KOF ECGI index	KOF
Gpat	Green patents	Number of patents	OECD Database
Egrowth	Economic Growth	GDP	World Bank

The geographic location of the sample economies is highlighted in map.

Figure 1: Geographic Location of Highly Financially Developed Economies



Our model is constructed in the following function:

$$CO_2 = f(Gpat, Ecg, Fin, EGrowth) \quad (1)$$

All continuous variables are transformed into log-form. The model specification is designed as follows:

$$CO_{2it} = \beta_0 + \beta_1 GPat_{it} + \beta_2 ECG_{it} + \beta_3 FIN_{it} + \beta_4 FIN_{it}^2 + \beta_5 EGrowth_{it} + \varepsilon_{it} \quad (2)$$

where β_0 is intercept, $\beta_1 - \beta_5$ are the estimated effects of linear and quadratic financial innovation along with green patents, economic globalization and economic growth of highly financially developed economies. Further, the ε_{it} is model residual of country i in year t. Within the equation, the quadratic value of financial innovation has been incorporated to accommodate the possibility of a non-linear association between financial innovation and environmental degradation. The primary estimation in our study is conducted using the Method of Moment Quantile Regression (MMQR). Producing these multiple quantile models is helpful to oversee the dynamic impact of independent variables on environmental quality among different quantiles, and hence become a strong basis for policy recommendation.

We preliminarily investigate all the variables using descriptive statistical tests based on mean, minimum, maximum, standard deviation, skewness, and kurtosis. We also investigate their normality distribution using the Jarque-Berra probability test. The normality test is executed as a justification for the use of MMQR as the primary method. Our preliminary analysis also includes cross-sectional dependence and homogeneity tests. Panel data can be vulnerable to cross-sectional dependence issues where the variables in the same cross-section are correlated. In detecting the presence of cross-sectional dependence, we run the cross-sectional dependence test from (Pesaran, 2004). Furthermore, for the sake of robustness, we also run the test by cross-sectional dependence (Chudik & Pesaran, 2015). Furthermore, we also run a slope heterogeneity test (Pesaran & Yamagata, 2008) to investigate whether the slope of the variables used is homogeneous. A heterogeneous slope may cause bias in fixed effect estimators.

In addition to cross-sectional dependence and homogeneity, ensuring that the statistical properties of the variables do not change over time is also important. Stationarity is a mandatory statistical property in our case, given that all of our variables are time series in nature. Hence, to ensure a robust stationarity of the variables, we applied two stationary tests. The first test is Im-Pesaran-Shin (IPS) (Im et al., 2003), a stationary test, while the second test is cross sectionally augmented IPS (CIPS), where both are tested with the null hypothesis that the variable is stationary.

4. Results and Discussions

This section carries a discussion of the diagnostic and the results of obtained estimates.

4.1 Descriptive Statistics

Table 2 describes the descriptive indicators of the variable used for carrying out the analysis. The carbon emission variable has been used in the logarithm for it has a positive mean value highest in magnitude. The mean value of green patents is also positive. Globalization is in index form having a positive mean. The variance of the financial innovation is the highest.

Table 2 Descriptive Statistics

	CO_2	$Gpat_{it}$	Ecg_{it}	Fin_{it}	$Egrowth_{it}$
Mean	12.4135	10.0791	79.8307	65.2093	4.0026
Minimum	10.2155	4.4301	48.5253	5.81003	-11.3554
Maximum	15.5692	26.44	90.8107	170.4082	23.6784
Std. Dev.	1.6040	3.7262	8.21779	35.5128	6.2333
Skewness	.28136	1.6378	-1.2457	.4434	1.9646
Kurtosis	2.0315	6.7637	4.7133	2.3367	6.3888
Probability	2.9e-04	1.5e-70	2.3e-26	3.5e-04	6.8e-80

4.2 Panel Diagnostics (Cross-sectional Dependence and Homogeneity Test)

Table 3 reports the tests of cross-sectional dependence and homogeneity. The results indicate the presence of cross-sectional dependence. For robustness, the cross-sectional dependence has been checked by Pesaran, (2004) and Pesaran CD test 2015. The results of both tests provide evidence of cross-sectional dependence in the panel. The absolute correlation values are also reported. The absolute correlation varies from .4-0.9. The results of the slope heterogeneity test of Pesaran & Yamagata, (2008) have been reported. The results indicate the heterogeneity of the slope coefficient.

Table 3 Cross-sectional Dependence and Homogeniety Test

Pesaran (2004) Test				Pesaran (2015) CD Test	
Variable	CD Test	Correlation	Abs. Corr.	Test Coefficient	mean abs(ρ)
CO_2	4.39***	0.117	0.561	6.174***	0.58
$Gpat_{it}$	27.58***	0.752	0.752	27.995***	0.75
Ecg_{it}	35.72***	0.973	0.973	36.356***	0.97
Fin_{it}	35.61***	0.970	0.970	35.891***	0.97
$Egrowth_{it}$	17.52***	0.478	0.480	18.96***	0.50
Slope Heterogeneity Test					
	$\widetilde{\Delta}$	$\widetilde{\Delta}_{adusted}$	Decision		
Statistics	22.469 (0.000)	25.080 (0.000)	Slope coefficients are heterogeneous		
*** shows significance at a 1%. Ho: cross-sections are independent.					

4.3 Stationarity Properties

Table 4: Unit Root Test Im, Pesaran and Shin

	CO_2	$Gpat_{it}$	Ecg_{it}	Fin_{it}	$Egrowth_{it}$
Level	-0.9707	-1.1065	-3.8403***	5.5453	-4.4152***
Difference	-5.3769***	-4.3607 ***	---	-2.2725**	---
Decision	I(1)	I(1)	I(0)	I(2)	I(0)
2nd Generation Unit Root Test (CIPS Test)					
Level	2.117	-1.889**	-1.385**	-0.141	-6.445***
Difference	-7.058***	-7.658***	---	-1.529**	---
Decision	I(1)	I(1)	I(0)	I(1)	I(0)

The unit root results have been reported in Table 4. The results indicate that the analysis is a combination of series with different integration orders. Economic globalization and economic growth are

stationary at the level. The financial innovation has highest integration order. The carbon emission and green patent are stationary at 1st difference. Table 4 shows the unit root results. According to the IPS test economic globalization and economic growth is stationary at level. The series of carbon emissions and green patents are integrated of order one. While the series of financial innovations is stationary at 3rd difference. The 2nd generation unit roots test has the advantage of taking the cross-sectional dependence and heterogeneity into consideration. Therefore, the results of the 2nd generation unit root test have also been reported. However, these provide the same results for the order of integration of the series.

4.4 Regression Estimates

The regression estimates are obtained by MMQR methodology and are presented in Table 5. The MMQR methodology carries the additional benefit of providing the estimates by sorting the dependent variable for the sample. The green patent is insignificant at the lower quantile, as it appeared significant at the 25th quantile. The variable is significant and negative at the highest (50th, 75th, and 90th) quantiles . The results indicate that an increase in green patents causes a decrease in carbon emission levels. Therefore, our results provide evidence in favor of green investment in reducing the emission levels in highly financially developed economies. The trend of the effect is highly supportive in protecting the environment of higher emission levels economies. The magnitude indicates that a unit increase in green patent decreases emissions by 5.2% to 8% from 25th to 90th quantiles, respectively. The trend of effect increases for high emitter economies. Therefore, it can be claimed that green investment can play a role in making the environment better. The effect of globalization is also supportive of the environment of economies with the highest financial development. The increase in economic globalization causes a decrease in the emission levels of these economies. The trend of the effect decreases as the emission levels are higher. The increase in globalization causes decreases in the emission level; therefore can be argued that with an increase in globalization, environmentally friendly goods are imported, which play a role in decreasing the emission levels. The financial innovation has been used in linear as well as quadratic form. Financial innovation is having a positive and significant effect on the emission levels of highly financially innovative economies. However, this effect is going to decrease as the emission levels are higher. The economic growth increases the emission levels however, the magnitude of the effect decreases for high emitters economies. The coefficient is high till the 50th quantile while it goes on to decrease for economies with higher emissions as for the highest quantile its magnitude decreases.

Table 5: Regression Estimates from MMQR

Variables	Location	Scale	Q25	Q50	Q75	Q90
$Gpat_{it}$	-0.0518***	-0.0193**	-0.0331	-.0525893**	-0.0701***	-0.0808***
	(0.006)	(0.042)	(0.141)	(0.0190909)	(0.000)	(0.000)
Ecg_{it}	-0.0943***	0.0130***	-0.1069***	-.093822***	-0.0820***	-0.0748***
	(0.000)	(0.001)	(0.000)	(.0076133)	(0.000)	(0.000)
Fin_{it}	0.0351	-0.0129***	0.0476***	.0345973***	0.0228**	0.0156
	(0.000) ***	(0.002)	(0.000)	(.0086084)	(0.009)	(0.104)
Fin_{it}^2	-0.0001	0.0001***	-0.0001 ***	-.0001123**	-0.0001	-0.0003
	(0.049)	(0.007)	(0.006)	(.0000591)	(0.500)	(0.963)
Eg_{it}	0 .1385***	-0.0195***	0.1575***	.1378012***	0.1200***	0.1092***
	(0.000)	(0.000)	(0.000)	(.007588)	(0.000)	(0.000)
Constant	18.2992***	0.5296***	18.8005***	18.32001***	18.9125***	19.0940***
	(0.000)	(0.055)	(0.000)	(.5522938)	(0.000)	(0.000)

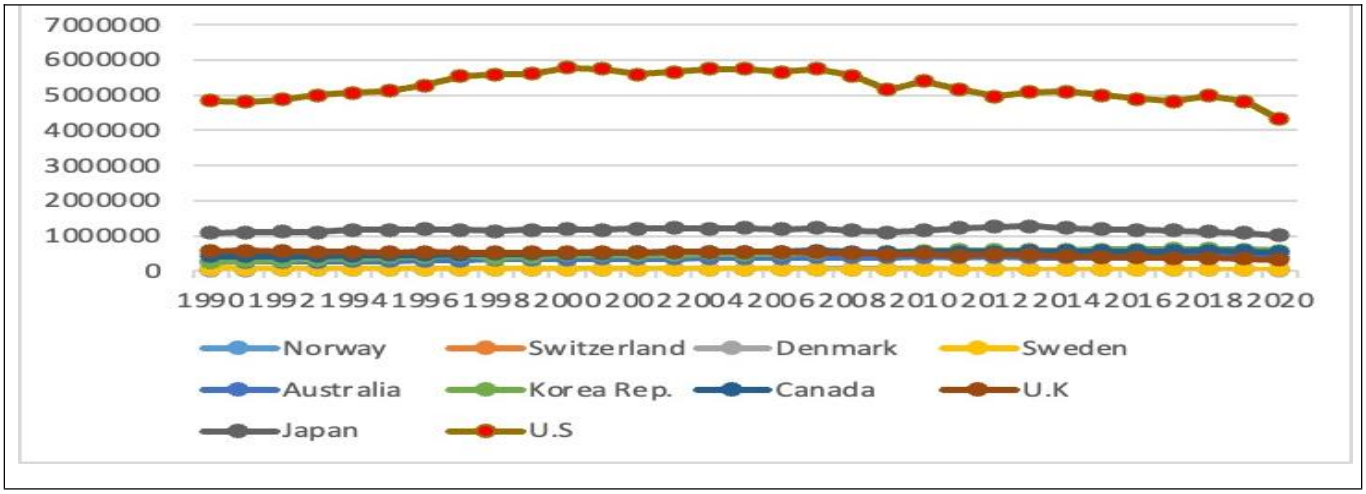
4.5 Discussion

The results have provided evidence in favor of green technology. For highly financially developed economies, green investments are significant and negative beyond 25th quantile, indicating a favorable impact on the environment. The results are justified based on the argument that environmental technologies limit emission levels. These technologies carry precedence over conventional sources of energy and maintain renewable sources of energy (Khan et al., 2022). Secondly, these technologies embody a particular feature of waste management and recycling. Therefore, production is accomplished efficiently (Mongo et al., 2021) as natural resources are shielded, which in turn improves the environment. The results of the analysis are aligned with Liu et al., (2021), and (Chen et al., 2023). The coefficient has an increasing trend over quantiles. The economies with higher levels of emission can decrease their environmental cost by investing in green technologies.

The globalisation coefficient is significant and negative across all the quantiles. Globalization has a favorable effect on the environment. The favorable effects can be justified based on the argument that globalization encourages specialization based on comparative advantage, allowing countries to produce goods more efficiently and with lower energy consumption. This specialization often results in the adoption of cleaner, more advanced technologies that reduce environmental degradation. In addition, there is greater access to environmentally friendly technologies and best practices through international trade and investment. Moreover, global integration increases awareness and accountability, as international environmental standards and regulations are more likely to be adopted under pressure from global institutions, trading partners, and environmentally conscious consumers. The results are partially aligned with Liu et al., (2021).

The results of the analysis for financial innovation are quite interesting. The effects of linear financial innovation are unfavorable to the environment of highly financially developed economies. This suggests that in such advanced financial systems, innovation may initially facilitate activities that contribute to environmental degradation, possibly through increased industrial output, resource exploitation, or promotion of carbon-intensive sectors. However, an interesting trend emerges when examining the behavior of financial innovation among high-emitting economies. In these cases, even linear financial innovation exhibits a declining trend in emissions, indicating that innovation might be leveraged more effectively toward sustainable practices where environmental pressures are more pronounced. This points to the possibility that high emitters are increasingly channelling financial innovation into greener technologies or cleaner production mechanisms, either due to regulatory pressure or increased environmental awareness.

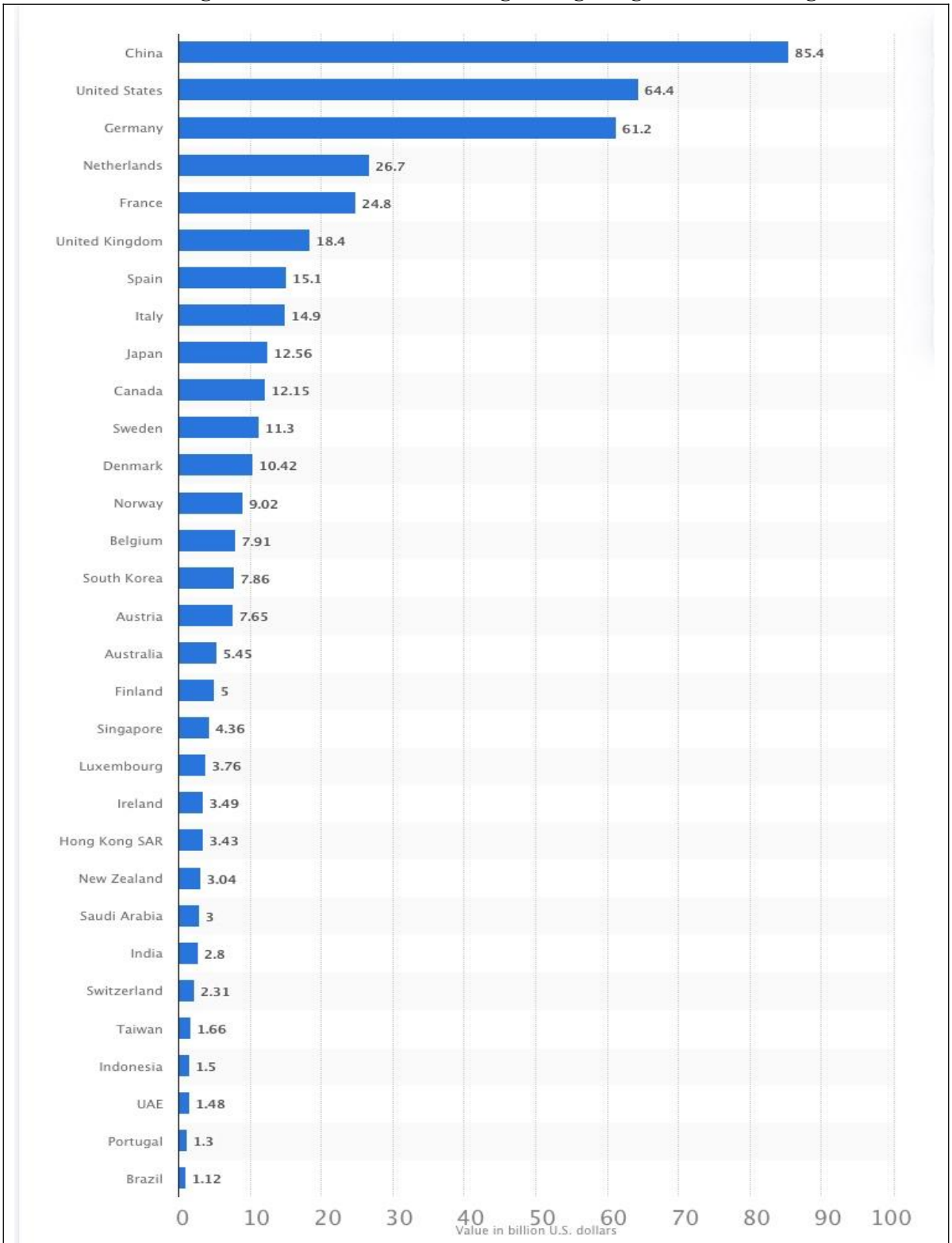
Figure 2: Emission level of highly financially developed Economies



Quadratic term of FIN contributes positively to environmental improvement across various quantiles. This favourable effect is most evident in the lower to mid quantiles, where the magnitude of the impact decreases steadily up to the 60th quantile. Interestingly, a reversal in trend occurs at the 70th quantile, where the magnitude of the effect increases, suggesting that financial innovation begins to regain its environmental

efficacy at higher levels of emissions or innovation intensity. To locate the economies lying in the 75th quantile the emission levels of sample countries over the sample period have been plotted in Figure 2.

Figure 3: List of countries among the highest green bond issuing



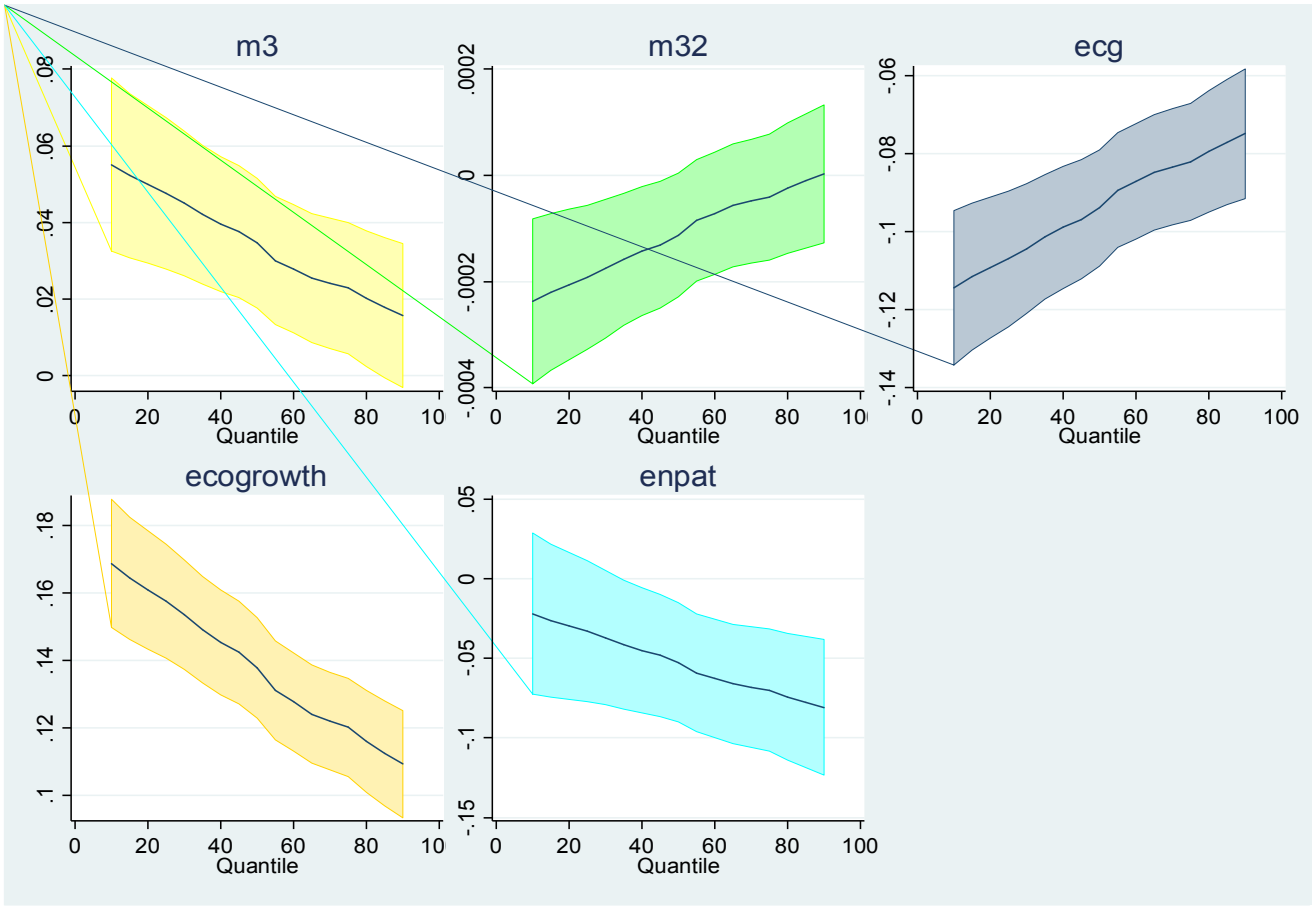
Source: statista.com

Canada and the United Kingdom come under the 75th quantile as per emission levels. United States and the United Kingdom are in quantile 70. For economies within the 70th quantile, the decline in emission is maximum. However, for economies lying in the 75th quantile the increase in financial innovation declines emissions with lesser magnitude.

The favorable impact of financial innovation can be justified based on the argument that higher financial innovation is directed to sustainable investment projects which transform the economies to be greener and direct it to environmental sustainability. Further, environment-related financial incentives e.g. issuance of green bonds and financial incentives to diminish the emission levels direct capital to environmentally favorable projects. Such projects nurture favorable environmental outcomes and play a role in declining emission levels (Dar & Asif, 2018) and (Acheampong, 2019). The results are aligned with (Khan et al., 2021) and (Acheampong, 2019) while are in contrast to (Cheng et al., 2021) and (Hafeez et al., 2018).

The number of issuance of green bond data as per country has been displayed in figure 3. The graph shows that followed from U.S 13 countries are from the sample for which the financial innovation results provide evidence of a favorable impact on the environment. The use of further instruments of financial innovation can enhance the favorable impact. The further instruments can be establishing green banks and green investment funds. The green banks particularly follow an objective to decrease costs related to ratepayers and expedite the process of transferring to low emission levels of carbon. Further, green investments allocate the resources to companies that promote environmentally friendly technology and conserve natural resources. The trend of graph of issuing green bonds of top 10 economies verify the favourable impact on environment.

Figure 4: Graphical Description of MMQR estimates



Source: Author Estimates

The figure 4 portrays the MMQR estimates in graph. The shaded color part indicates the 95% confidence interval of the estimated parameter. The x-axis presents the quantiles however the elasticity of each variable is taken on the y-axis.

4.5 Robustness of Regression Estimates

Table: 6 Robustness of Regression Estimates

Variable	Quantile 25	Quantile 75
$Gpat_{it}$	-.0331504**	-.095804***
Ecg_{it}	-.114904***	-.049009***
Fin_{it}	.051218***	.034748***
Fin_{it}^2	-.000232***	-.000148***
$Egrowth_{it}$	.189148***	.113016***
$Constant$	18.33269	16.3568***

The robustness of the estimates has been checked by bootstrap quantile regression. The results for quantiles 25th and 75th have been reported in table 6. The results indicate the robustness of the estimate. The results from bootstrap quantile regression are approximately the same except for minor differences. The use of bootstrap quantile regression confirms the reliability of the MMQR estimates.

5. Conclusion

The study follows the objectives to analyze the linear and non-linear impacts of financial innovation on the emission levels of highly financially developed economies. The MMQR methodology has been utilized to obtain the long-run estimates for the sample economies. The green patent coefficient appears significant at the 30th quantile while it carries a favorable effect on the environment of highly financially developed economies. Further, its trend is again supportive as its magnitude increases along higher quantiles. The potential reason is that countries with lesser emission can be using energy optimally therefore the incremental benefits of the additional patents decreases.

Further, emission in some economies can be from sectors except industry, where green technologies can have lesser impact. The effect of globalization is also supportive of the environment of economies, while the trend of the effect goes on decreasing as the emission levels are higher. The linear and non-linear effects of financial innovation have been captured for variation in emission levels. The linear coefficient is unfavorable to the environment. However, this effect is going to decrease as the emission levels are higher. Further, the coefficient is insignificant for the highest quantile. The coefficient of the non-linear term is negative and is supportive of the environment. However, the magnitude of the effect increases at the 70th quantile and then decreases onward. The magnitude of the financial innovation non-linear term presents variation in magnitude. It follows a decreasing trend till the 60th quantile while its magnitude jumps highest at the 70th quantile moves to the lowest again, and then follows an increasing trend. Therefore, it can be argued that a low level of financial innovation damages the environment. While higher financial innovation is environmentally friendly.

The economic growth affects the emission levels positively however, the magnitude of the effect decreases for high emitters economies. The trend of the coefficient is high till the 50th quantile while it decreases for economies with higher emissions.

6. Policy Implication and Future Direction

The study has analyzed a vital issue related to the spread of financial innovations. Financial innovation is an important determinant of environmental sustainability. However, the insignificance of green patents at lower quantile implies that green technologies be deployed in high emission regions. Further, the tax credits and

grants in low emission regions can incentivize the adoption of green technologies. The positivity of linear term of finacial innovation implies to impose restriction on carbon intensive financial products. The incentivizing the green financial products e.g renewable energy funds and green bonds can decline the emission levels of the economies.

The implication from the analysis is quite convincing on the argument that highly financially developed economies should take certain steps to reap a full benefit from financial innovation. The initiation of weather derivatives as financial instruments will help manage risks related to weather conditions caused by higher emission levels. The weather derivative are instrument of financial innovation where a company or individual can hedge due to facing any weather-related risk. The launching of environment-friendly financial innovation particularly for economies under the 70th quantile will provide them with multiple benefits.

The use of further instruments of financial innovation can enhance the favorable impact. Further instruments can be establishing green banks (the institutional setup of financial institutions that aims to decline energy-related costs enhance the private sector investment and accelerate the transformation to lower emission levels) and green investment funds (the investment instruments that allow investments in companies that play a direct role for in environmental sustainability). Further, the favorable and declining impact of globalization on emission levels of financially developed economies calls for the import of environmentally friendly technologies. Environmental-friendly technologies can play a prominent role in making the environment better. The future direction of the research area can be to evaluate the financial innovation and environment nexus for economies with heterogeneous levels of financial development. Their clear role can be evaluated by exploring the effects of particular innovations prevalent in these economies.

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