THE ROLES OF INFORMATION AND COMMUNICATION TECHNOLOGIES, GREEN INNOVATION, AND GLOBALIZATION IN DRIVING CARBON EMISSIONS IN G-20 COUNTRIES

YAP LE TING

BACHELOR OF ECONOMICS (HONOURS)
GLOBAL ECONOMICS

UNIVERSITI TUNKU ABDUL RAHMAN

FACULTY OF ACCOUNTANCY AND MANAGEMENT
DEPARTMENT OF ECONOMICS

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The roles of Information and Communication Technologies, Green innovation, and Globalization in driving Carbon Emissions in G-20 countries

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YAP LE TING

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DECLARATION

We hereby declare that:

(1) This undergraduate research project is the end result of our own work and that due acknowledgement has been given in the references to ALL sources of information be they printed, electronic, or personal.

(2) No portion of this research project has been submitted in support of any application for any other degree or qualification of this or any other university, or other institutes of learning.

(3) Equal contribution has been made by each group member in completing the research project.

(4) The word count of this research report is 11440.

Name of Student:	Student ID:	Signature:
Yap Le Ting	19UKB01852	

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DEDICATION

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Page

LIST OF ABBREVIATIONS

CO2	Carbon Dioxide
COP21	Paris Climate Conference
EKC	Environmental Kuznet Curve
EU	European Union
GDP	Gross Domestic Product
GHG	Greenhouse Gases
HGE	High-Globalized Economies
ICT	Information and Communication Technlogies
IOM	Integrated Ocean Management
LGE	Low-Globalized Economies
OECD	Organisation for Economic Co-operation and Development
OLS	Ordinary Least Squares
SDG	Sustainable Development Goals
SSEA	Statistical Package for Social Science
UNEP	Statistical Package for Social Science

PREFACE

Over the last century, many countries have been primarily focused on economic growth and development. However, this focus has often come at a significant cost to the environment. Actions such as industrialization, transportation, and agriculture have led to environmental degradation and pollution, with climate change being one of the most severe consequences. The effects of climate change are not limited to the environment but also have profound social and economic consequences, affecting everything from money to lives. In light of these challenges, there is an urgent need for collective action and innovative solutions to mitigate and adapt to the impacts of climate change.

The role of Information and Communication Technology (ICT), green innovation, and globalization in shaping environmental quality and addressing climate change is a topic of growing interest in academic, policy, and business circles. The intersection of these three factors has the potential to transform how human produce and consume goods and services, impacting the environment and climate.

The research investigates the relationship between ICT, green innovation, and globalization across different countries with different levels of carbon dioxide emissions. This research provides insights into the nexus between the variables and enables the governments to design a better policy to promote sustainable growth.

ABSTRACT

To combat global climate change, it is necessary for all nations to make collective efforts towards integrated, sustainable, and innovative technologies. This study intends to investigate the roles of Information and Communication Technologies (ICT), green innovation and globalization on carbon dioxide (CO2) emissions in G20 countries by employing a quantile regression analysis. The research also explores the existence of the Environmental Kuznets Curve (EKC) in these countries. The results suggest that the effects of ICT, green innovation, and globalization vary depending on the level of carbon dioxide emissions. Even though the findings indicate ICT and green innovation exacerbated CO2 emissions in the lower CO2 emissions countries and in the majority of G20 countries respectively, the globalization was found to reduce the CO2 emissions in high CO2 emissions countries. As for the EKC hypothesis, it is found to be valid for ICT in low carbon emissions countries, green innovation in medium to high carbon emissions countries, and globalization in high carbon emissions countries. The outcomes of this research could assist policymakers in better understanding the factors driving CO2 emissions and the potential for ICT, green innovation, and globalization to mitigate air pollution in BRI countries.

Keywords: G20, Carbon Dioxide, Information and Communication Technologies, Green Innovation, Globalization, Quantile Regression

CHAPTER 1 INTRODUCTION

1.0 Introduction

This chapter provides an overview of this study. Section 1.1 discussed the research background of the study. Section 1.2 consists of the problem statement, in which the motivation for the study is discussed. Section 1.3 and Section 1.4 comprise the research objective and research question respectively. The significance of the study will be discussed in 1.5, in which the contribution of this study is provided. Next, the chapter layout is displayed in Section 1.6. Lastly, the conclusion will sum up in Section 1.7.

1.1 Research Background

The world is in the midst of the fourth industrial revolution, which conceptualizes the rapid transformation and growth of technologies, industries, and societal patterns (Zemlyak et al., 2022). Its characteristics include automation, robotization, and increasing reliance on digital technology in sectors like logistics, services, production, and transportation (Mazur, 2023). Digitalization advancement had dramatically boosted economic growth and eliminated a large scale of poverty, yet it has also driven global greenhouse emissions. In meeting the energy demand of developing nations, fossil fuel energy has locked in a significant amount of greenhouse gas emissions over the years (Edziah et al., 2022). According to Kahouli et al. (2022), fossil fuel energy including natural gas, coal, and oil are claimed to be the most crucial ones in the world, as they account for more than 80% of the total energy sources. Hence, economic development and the environmental quality association remain hot in this Anthropocene era.

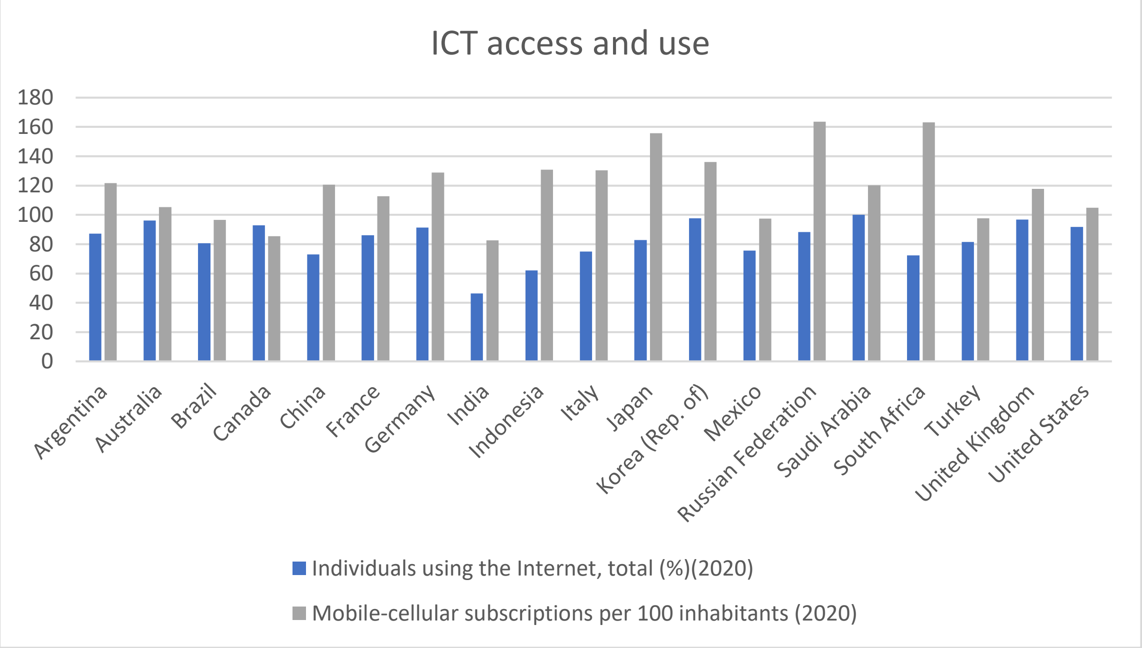
Environmental deterioration, or more specifically, climate change is currently a global consensus that transcends national boundaries. The sea levels are dramatically rising, the glaciers and ice sheets are rapidly melting, and intense drought events are frequently happening (Nguyen et al., 2020). Carbon dioxide (CO2) from energy consumption is claimed to be the main cause of climate change (Kasman and Duman, 2015). According to the UNEP

Emissions Gap Report 2022, the world must cut off emissions by 45% to prevent a global catastrophe. The serious consequences threatened the lives of human and natural wildlife communities and required urgent responses relative to the issues. In 2015, the Paris Agreement came into force to strengthen the consequences of climate change. Its target is to keep global warming far below 2 degrees Celcius, ideally below 1.5 degrees Celcius. Another urgent call for action, the Sustainable Development Goals (SDGs) was introduced by the United Nations. It is a blueprint for peace and prosperity for humans and the earth to address challenging issues including reducing poverty, improving health and education, stimulating economic growth, and combatting climate change. Among the 17 SDGs goals, 6 are related to the protection of the environment. SDG 6 focuses on providing clean water and sanitation while improving water quality and sustainability. SDG 7 aims to make energy accessible and promote renewable energy sources and efficiency. SDG 12 emphasizes responsible consumption and production patterns, reducing waste, improving resource efficiency, and encouraging sustainable practices in industries. SDG 13 seeks to address climate change through mitigation, adaptation, impact reduction, and early warning. SDG 14 focuses on conserving and sustainably using marine resources by reducing pollution, protecting ecosystems, and supporting small-scale fishers. Finally, SDG 15 aims to protect and restore terrestrial ecosystems, manage forests sustainably, combat desertification, halt, and reverse land degradation, and prevent biodiversity loss (United Nations, 2022). Overall, this had shown that society's concern over environmental deterioration was aroused along with the soaring industrialization and economic development**.**

Following the fourth industrial revolution, the Information and Communication Technologies (ICT) infrastructure experienced significant improvement (Nguyen et al., 2020). In the industrialization 4.0 process, much emphasis is given to ICT radically altering how all business activities are carried out. Meanwhile, the environmental impact of ICT penetration is gaining a great amount of attention due to the increase in greenhouse gases (GHGs) brought on by the extensive use of ICT products. The GHG emissions were estimated to exceed 14% of 2016 by 2040 if there is no effective measure adopted. While ICT penetration emits greenhouse gases, it may decrease environmental degradation, depending on how the technologies have been used (Tahsin, 2022). Another important element in the fourth industrial revolution is globalization. It acts as a catalyst for the improvement of productivity and income by stimulating the flow of goods, human capital, currencies, and technologies across nations (Shan Lee et al., 2020). In this setting, concerns about the impact of globalization are on the rise. Particularly, the global environmental impact has drawn the interest of policymakers and academia (Nan et al., 2022). To tackle environmental problems, the concept of "green innovation" has been introduced. It is expected to aid in greenhouse gas emissions and potentially reverse the consequences of climate change by creating and deploying innovative technologies and methods (Shao et al., 2021).

In G-20 economies, the implementation and usage of digital technologies vary as influenced by factors such as demographic characteristics, industries, and business sizes. According to Figure 1 presented below, South Korea, Saudi Arabia, Canada, the United Kingdom, and Japan have surpassed the 90% mark in terms of the proportion of their populations using the Internet. On the other hand, Indonesia and India are still lagging behind with less than 50% of their populations using the Internet. Additionally, South Africa, Russia, and Japan have the highest number of mobile-cellular telephone subscriptions (Ministry of Communications and Informatics Republic of Indonesia, 2022). Hence, the uneven gaps in ICT development in the G20 countries have sparked concerns regarding the inclusivity of digital transformation.

Figure 1.1: The ICT access and use for G20 countries in 2020



Adapted from: World Bank (2021)

Currently, the G-20 is committed to the 2030 Agenda for Sustainable Development (Elgar et al., 2019). A report by OECD revealed that 16 members of the G20 have formulated national adaptation plans (NAPs) as strategic responses to climate change, an increase from 10 members in 2015. Adding to the list, Argentina and Russia are currently developing NAPs. The climate change adaptation plans and strategies by G-20 members are summarised in Table 2 below. The significance of NAPs lies in their ability to aid countries in adapting to climate change, enhancing resilience, and reducing risk. Besides, the G-20 nations are also dedicated to green finance and marine protection. As a result, global green bond issuance has grown exponentially, reaching USD 167.3 billion in 2018 from a mere USD 2.6 billion in 2012. The coverage of Marine Protected Areas in G20 countries is increasing at a much faster rate compared to the rest of the world. In the 2000s, MPAs in G20 countries accounted for 4.2% of the total marine areas under national jurisdiction protection, and this has increased to 16.5% in recent years (Elgar et al., 2019). In summary, G-20 members are actively engaging in initiatives related to environmental issues.

Table 1.1: Climate change adaptation plans and strategies by G-20 members

Country	Name	Year
Argentina	*Under development*	-
Australia	National Climate Resilience and Adaptation Strategy	2015
Brazil	National Adaptation Plan	2016
Canada	Pan-Canadian Framework on Clean Growth and Climate Change	2016
China	National Strategy for Climate Adaptation	2013
France	2nd National Adaptation Plan	2018
Germany	Adaptation Action Plan	2011
India	National Action Plan on Climate Change 2008	2008
Indonesia	National Action Plan on Climate Change Adaptation (RAN-API)	2013
Italy	National Adaptation Strategy	2014
Japan	Updated National Adaptation Plan (Based on the new Adaptation Act)	2018
Mexico	Special Climate Change Programme	2014
Russia	*Under development*	-
Saudi Arabia	--	-
South Africa	National Adaptation Strategy	2016
Republic of Korea	2nd National Adaptation Plan	2016
Turkey	National Adaptation Plan	2011
United Kingdom	National Adaptation Plan	2013
United States	--	-
European Union	EU Adaptation Strategy	2013

Source: OECD. (2019). Implementing adaptation policies: towards sustainable development Issue Brief.

Within the G-20 nations, globalization is often discussed in relation to various economic, financial, social, environmental, and governance issues that have global implications. For example, discussions on international trade, investment, finance, development, climate change, technological advancements, labor, migration, health, and other global challenges. To date, some notable achievements of the G20 collaboration are the implementation of tangible measures, including targets, to foster sustainable growth and global stability. Efforts have been made towards cooperation on tax transparency, resulting in the identification of an additional USD 95 billion in revenue since 2009. Steps have been taken to lower the cost of remittances, with projections of generating at least USD 25 billion annually by 2030. Progress has been made in increasing female workforce participation and reducing the gender gap by 25% by 2025. The G20 has also played a role in promoting dialogue and building consensus on trade and investment matters.

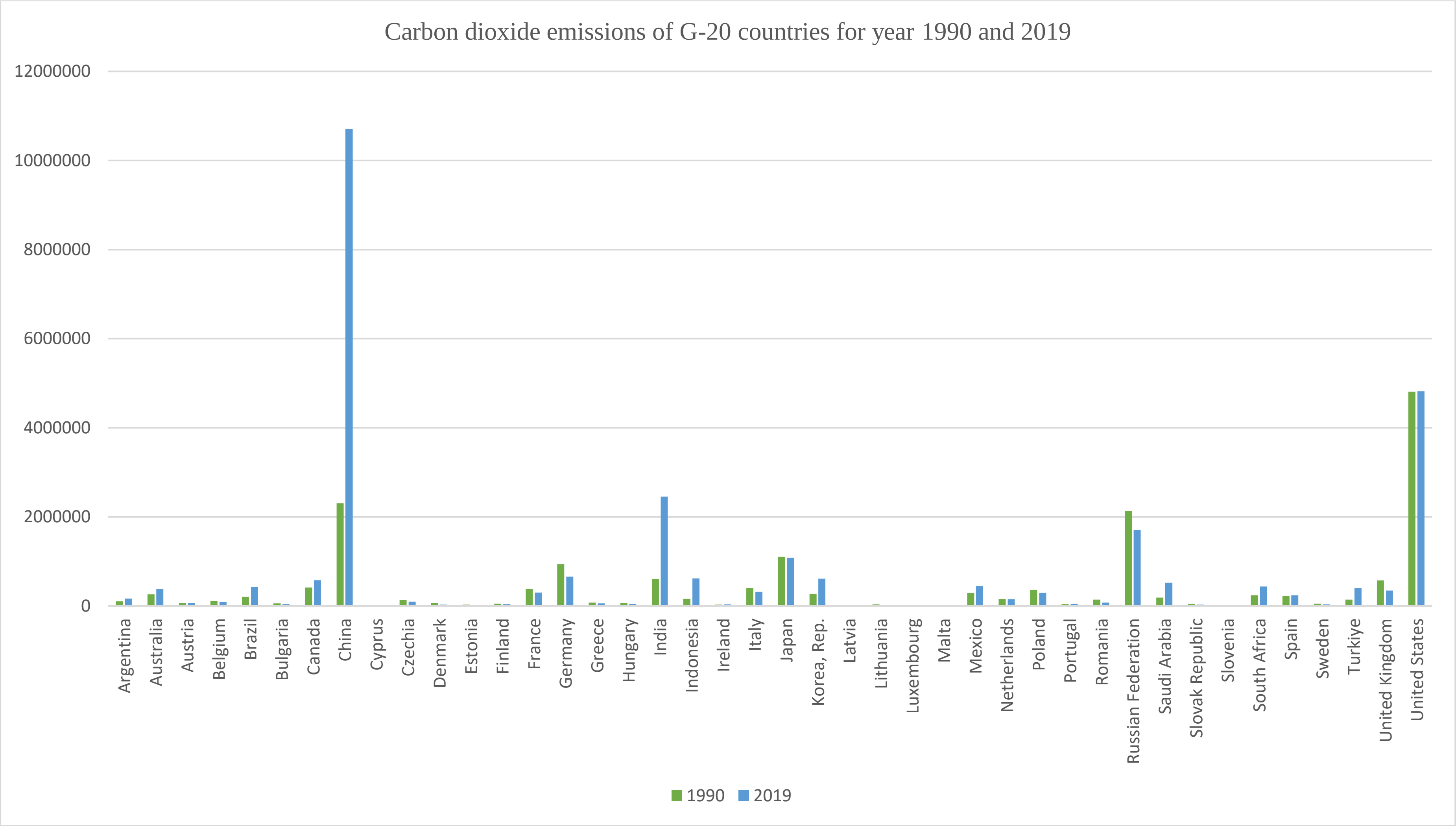
1.2 Problem Statement

The primary objective of the present research is to highlight the degradation of the environment and the role of information and communication technologies (ICT), green innovation, and globalization in the economies of the G-20 countries. Specifically, this study focuses on the G20, which was established in 1999 and comprises 19 countries and the European Union (EU). The G20 is a prominent group with significant global influence, and our research aims to investigate the impact of ICT, green innovation, and globalization on carbon dioxide emissions. The G20 countries are often chosen for scholarly analysis due to their prominent role in global economic growth. The main justification of this study to focus on G20 economies is their demonstrated ability and capability to depict global trends. The G20 represents a significant portion of the world's population, accounting for two-thirds of the total global population, 80% of the world's GDP, and three-quarters of international trade. Moreover, G20 countries account for more than 80% of total international material consumption and production. Additionally, the G20 comprises a diverse mix of countries, including 8 developed countries (the United States, the United Kingdom, Japan, Canada, Australia, Italy, Germany, and France), 11 developing countries (China, Russia Federation, Brazil, India, Argentina, Mexico, Indonesia, South Africa, Saudi Arabia, Turkey, and the Republic of Korea), and the European Union (EU). By studying the G20 countries collectively, more meaningful results, considering the notable disparities between developed and developing countries may be obtained.

Between 1990 to 2014, the G20's carbon emissions increased tremendously by 56% due to their continued reliance on fossil fuels and the highest levels of fossil fuel subsidies. To tackle the global challenges, the G20 members are dedicated to working together on climate change mitigation through green innovation such as the transition from primary energy to renewable energy. This transition is significant and is predicted to eliminate carbon dioxide (CO2) emissions by 28% in 2030. In 2018, the G20 reported approximately 1.8% of carbon dioxide (CO2) emissions due to rising demand and economic development. Although there was a 5% rise in G20 renewable energy consumption, fossil fuels still make up approximately 82 percent of the energy supply in member nations, with Saudi Arabia, Australia, and Japan contributing more than 90 percent of the total (Bhat et al., 2022).

The figure below compares the CO2 emissions for the years 1990 and 2019 for the G20 countries. Based on the diagram below, CO2 emissions in each country is different, therefore is important to study the impact of ICT, green innovation, and globalization on a different level of CO2.

Figure 1.2: The carbon dioxide emissions of G20 countries for the years 1990 and 2019



Source: World Bank (2020)

1.3 Research Objectives

The main objective of this study is to investigate the influences of information and communication technologies (ICT), green innovation, and globalization on carbon dioxide (CO2) in G20 countries across different quantiles.

The specific objective of this study is:

1. To ascertain the causal linkages among Information and Communication Technologies, green innovation, and globalization with carbon dioxide emissions in G20 countries across different quantiles.
2. To analyze the existence of the Environmental Kuznets Curve (EKC) relationship between Information and Communication Technologies, green innovation, globalization, and carbon dioxide emissions in G20 countries across different quantiles.

1.4 Research Questions

This study will answer the following questions:
How can information and communication technologies (ICT), green innovation, and globalization influence carbon dioxide (CO2) emissions?

1.5 Significant of the Study

The study aims to provide a clearer picture for the authorities in designing and implementing green technology policies to mitigate the environmental impact of economic activities. Currently, there is a limited paper that conducts research on the topic of how information and communication technologies (ICT), green innovation, and globalization affect carbon dioxide (CO2) in G-20 countries. Therefore, this study would like to fill up the gap and expand the research of Nguyen et al. (2020) by adding the green innovation variable into the context. By utilizing the quantile regression, this research explores how information and communication technologies (ICT), green innovation, and globalization affect different carbon dioxide (CO2) emissions quantiles of the G-20 countries for the period between 1970 to 2019.

1.6 Chapter Layout

The following parts of this paper are structured as below. Chapter 2 consists of the related reviews done by previous studies and a discussion about the relationship between the dependent and independent variables. Next, Chapter 3 will discuss the research methods and the data collected. In Chapter 4, the empirical results is being discussed. Finally, Chapter 5 will wrap up the whole study and provide recommendations for future studies.

1.7 Conclusion

In this chapter, we have provided an overview of the research background and problem statement. We also crafted the research objectives and questions in the following parts. Lastly, the significance of this study is highlighted. In the next chapter, we will look into the empirical results of the previous studies.

CHAPTER 2 LITERATURE REVIEW

2.0 Introduction

The nexus between Information and Communication Technologies (ICT), globalization, green innovation, economic growth, and environmental degradation has been investigated in previous studies, yet they showed a heterogeneous outcome. The variation in the method used location, and economic level are examples of factors that cause heterogeneity in the results. In Section 2.1, the linkage between ICT, economic growth, and CO_2 provided by the empirical results is discussed. In Section 2.2, we discussed the relationship between green innovation, economic growth, and CO_2. In Section 2.3, we looked into the linkage between globalization, economic growth, and CO_2. In the next part, Section 2.4, a brief introduction of the theoretical model, which is the Environmental Kuznets Curve is provided. Next, we developed the hypothesis of this research in Section 2.5. In Section 2.6,

2.1 Review of theoretical models

2.1.1 The Environmental Kuznets Curve

The EKC theory states that environmental degradation rises as an economy develops and that once economic activity reaches a certain point, environmental degradation begins to decline with further economic advancement (Shahbaz and Sinha, 2019). The theory is based on the idea that as a country becomes wealthier, it can afford to invest in cleaner technologies and environmental protection measures, leading to a reduction in pollution levels. Although initially attractive, the EKC hypothesis and its associated policy implications have increasingly come under scrutiny and criticism by both theoretical and empirical literature (Chiu, 2012; Stern, 2017). There are four effects that can impact the relationship between economic growth and environmental degradation: (i) the Scale Effect, in which emissions increase as the economy grows larger in scale; (ii) the Output Effect, in which the structure of production shifts towards more sophisticated, higher value-added activities that result in reduced emissions per unit of output; (iii) the Input Effect, in which emissions-producing units shift towards less environmentally damaging inputs, which also reduces emissions per unit of output; and (iv) the Technology Effect, in which new technologies enable changes in production processes that improve production or delivery methods. While the Scale Effect tends to dominate in the early stages of economic growth, the other effects become more significant in later stages. The inverted U-shape of the EKC emerges when the combination of input, output, and technology effects outweighs the scale effect (Añón Higón et al., 2017).

At the outset, the introduction of information and communication technologies (ICT) into firms is typically a part of the growth process and contributes to firm expansion, thus leading to greater emissions due to the scale effect. If the ICT adopted includes heavy computing and software components, it has been shown to increase emissions, in contrast to communications devices, which have been found to reduce emissions. In such cases, emissions would increase with the adoption of ICT. However, once this basic ICT infrastructure is in place, marginal ICT investments could go towards optimizing production processes, thereby increasing energy efficiency and reducing emission intensity through the technology effect. Additionally, the input and output effects are also possible if ICT enables the use of cleaner inputs or the production of more ICT-based output (Añón Higón et al., 2017). In order to expand the scope of the EKC hypothesis, the relationship between the environment and information and communication technology (ICT) is explored, with the assumption that once a certain level of ICT development is achieved, it has the potential to reduce CO2 emissions in G-20 countries.

One of the primary criticisms levied against the hypothesis is that the typical shape of an EKC curve is predicated on the assumption that environmental pollution is not cumulative or that its effects can be reversed (Fodha and Zaghdoud, 2010). While the EKC may be appealing to those concerned with environmental quality and progress, it fails to account for the cumulative nature of CO2 emissions and the irreversible damage caused by biodiversity loss (Fodha and Zaghdoud, 2010; Cole, 2003).

The second critique of the EKC hypothesis is that empirical studies on the subject may only demonstrate local and regional effectiveness, and not translate to significant global outcomes due to the relocation of polluting industries from developed to developing countries (Aydin et al., 2019). As a result, while pollution levels may decrease in developed countries, developing nations that receive foreign direct investment from these industries may experience higher levels of environmental degradation (Aydin et al., 2019). Essentially, the inverted-U shape of the EKC is a byproduct of developed countries exporting pollution to countries with weaker environmental regulations, a phenomenon that has been referred to as pollution havens (Kearsley and Riddel, 2010).

2.1.2 The Use Effect, The Substitution Effect, and The Cost Effect

The impact of ICT on environmental quality can be divided into three kinds of effects which are the use effect, the substitution effect, and the cost effect. In terms of the use effect of ICT, the production cycle which comprises manufacturing, processing, distribution, and maintenance is taken into account (Dehghan Shabani & Shahnazi, 2019). The manufacturing process consumes a substantial amount of electricity and led to carbon dioxide increment (Malmodin & Lundén, 2018). Besides, the e-waste produced through the consumption of ICT equipment in the manufacturing process might stimulate carbon dioxide emissions (Danish et al., 2018). Next, the substitution effect of ICT refers to the replacement of older technology with newer technology and this will result in an increase in production efficiency through a number of causes (N'dri et al., 2021). For example, internet and telecommunication (Datta & Agarwal, 2004, Ozcan & Apergis, 2018), smart transportation (Cohen-Blankshtain & Rotem-Mindali, 2016), and energy management (Liu et al., 2022). Furthermore, the third effect, which refers to the cost effect has to do with how ICT affects the surge in demand for other products and services brought on by lower costs. This result leads to an increase in energy use and CO2 emissions (Dehghan Shabani & Shahnazi, 2019).

2.1.3 Porter Hypothesis

The Porter Hypothesis is an economic theory proposed by Harvard Business School professor Michael Porter in the 1990s. The hypothesis suggests that environmental regulations and policies can stimulate innovation, leading to more efficient use of resources and increased competitiveness for firms (Porter and Van Der Linde, 1995). Currently, research on the impact of regulations on innovation and efficiency gains can be broadly categorized into two perspectives: the compliance cost effect and the innovation offset effect.

The compliance cost effect of the Porter Hypothesis refers to the idea that environmental regulations can impose additional costs on businesses, which can lead to reduced profitability and hinder innovation. This perspective suggests that the costs of compliance with environmental regulations may outweigh the benefits of innovation and that the regulations may ultimately be counterproductive. The innovation offset the effect of the Porter Hypothesis suggesting that environmental regulations can stimulate innovation and lead to increased efficiency gains for businesses. This perspective suggests that firms that are subject to environmental regulations may develop new technologies or processes that reduce their environmental impact, which can result in cost savings and improved competitiveness. The innovation offset effect implies that environmental regulations can provide firms with the incentive to innovate, leading to a more sustainable and efficient economy (Porter, 1991; Porter and Van Der Linde, 1995; Leeuwen & Mohnen, 2017; Wang et al., 2022; Leeuwen & Mohnen, 2017)

2.1.4 Globalization income effect, technique effect, and composition effect

The income effect, the technique effect, and the composition effect are three important impacts of globalization on the economy. The **income effect** stated that increased globalization results in increased trade and manufacturing, which raises CO2 emissions and signifies a decline in environmental quality (Jena & Grote, 2008). Next, the **technique effect** refers to the greater opportunities as a result of globalization for nations to access worldwide markets and acquire energy-efficient technologies, which ultimately lowers CO2 emissions levels (Dasgupta et al., 2006). Lastly, the **composition effect** is defined by the changes in the capital-labor ratio due to the changes in the economic structure. For example, if an economy swift from the agricultural to the manufacturing sector, the CO2 will increase, on the other hand, if it is further extended from the manufacturing to the services sector, the CO2 will reduce (Shahbaz et al., 2018).

2.2 ICT, and CO_2 emissions

The widespread use and adoption of ICT are commonly seen as beneficial to society and the economy as it offers a broad range of opportunities, cost savings, and conveniences such as fostering technological innovation, improving productivity, and facilitating human communication (Melville & Ross, 2016; Chun et al., 2015; Olesen and Myers, 2013). However, there is no clear consensus on its environmental impact. Some studies claimed that the utilization of ICT in creating more economic incentives and facilitating superior environmental management could potentially yield environmental benefits. On the other hand, some researchers have raised apprehensions regarding the negative impact of ICT on the environment due to factors such as high internet and mobile phone usage.

A positive relationship between ICT and carbon dioxide emissions was found by Park et al. (2018) for European Union countries, Asongu et al. (2018) and Avom et al. (2020) for sub-Saharan African countries, Tsaurai & Chimbo (2019) for emerging economies, Arshad et al. (2020) for South and Southeast Asian (SSEA) region, and Raheem et al. (2020) for the G7 countries in the long run. This means that ICT is raising the threat to environmental quality by increasing CO_2 emissions. In contrast, Haseeb et al. (2019), Kahouli et al. (2022), Danish et al. (2018), and Shaaban-Nejad & Shirazi (2022) maintained that ICT could mitigate CO2 emissions. On the other hand, some researchers claimed that the results of ICT on CO2 emissions are different based on the developing levels. For instance, Khan et al., (2020), Arshad et al. (2020), and Majeed et al. (2018) found that ICT could mitigate emissions in developed countries but not in developing countries while Ozcan & Apergis (2018) conclude that ICT could reduce carbon emissions in developing countries. Additionally, Lee, Liew, et al. (2022) investigation showed that telephone and mobile usage could decrease carbon dioxide emissions while internet usage aggravated environmental degradation. Furthermore, an inverted U-shape between ICT and carbon dioxide emission has been confirmed by several empirical studies (Añón Higón et al., 2017, Faisal et al., 2020). The inverted U-shape relationship implies that the ICT first degrades the environment, and it improves the quality by controlling the CO2 as time passes. In this case, further investigation is needed to confirm the impact of ICT on CO2 emissions. Hence, we formed two hypotheses, which are the significant positive linear relationship and the inverted U-shape relationship between ICT and CO2 emissions.

2.3 Green Innovation, and CO_2 Emissions

The term "green innovation" refers to process and product innovations with the aim of minimizing harmful environmental effects that frequently result from economic activity (Schiederig et al., 2011). By reducing the internal conflicts between economic growth and environmental degradation, green technological innovation is seen as a crucial tool in reducing the burden on resources and the environment as economic activity is modernized (Gao et al., 2018, Zhang, Liu, Zheng, & Xue, 2017).

Numerous studies have looked into the connection between environmental quality and green technological innovation, with varying outcomes. Several studies concluded that green innovation including investment in green research and development (R&D), implementation of carbon capture technology, application of green patents, and consumption of renewable energy sources could reduce carbon dioxide (Lee and Min, 2015; Díaz, Fernández, Gibbins, and Lucquiaud, 2016; Tahsin, 2022; Khan et al., 2021; Cho and Sohn, 2018; Sun et al., 2008; Cetin, 2018; Bhat et al., 2022). Additionally, López et al. (2019) suggested that the promotion of technological innovations including electric buses and emission-free buses could help to achieve a better environmental dimension, while Chishti et al. (2021) proposed that energy innovation could increase environmental sustainability. Furthermore, Choudhary et al. (2021) and Winther et al. (2020) supported that innovation in the blue economy such as integrated ocean management (IOM), has the potential to significantly mitigate the negative impact of GHG emissions on biodiversity and the environment. A significant advantage of green technological innovation is the potential to substantially reduce the costs of carbon mitigation by creating more cost-effective and energy-efficient technologies (Popp, 2012). However, Mohd Suki et al. (2022) revealed that there is a negative correlation between technological innovation, renewable energy, and carbon emissions from production.

Despite the negative relationship between green innovation and carbon dioxide has been confirmed by a number of previous studies, different results have been found in the other works of literature. Toebelmann and Wendler (2020) revealed that environmental innovation reduces CO2 emissions, but general innovative activity has an increasing effect on CO2 emissions. By employing the data from 70 countries, Su and Moaniba (2017) summarized that climate-change innovation increases the carbon emissions from gas and liquid fuels while decreasing the carbon releases from solid fuel burning. Du and Li (2019) claimed that the linkage between green technology innovation and CO2 differs according to the income level of the countries. The results showed that high-income countries have a significant relationship while low-income countries have a non-significant relationship with the connection between green technology innovation and CO2. Furthermore, some authors categorized the impact of green innovation on CO2 based on different sectors. Technology innovation was proven to have no significant effect on the energy and transport sector, while technology innovation decreases CO2 emissions in the industrial sector (Erdogˇan et al., 2020; Zheng et al., 2021). Wang et al. (2012) results showed that patents for fossil-fueled technologies could not reduce carbon emissions, while the patents for carbon-free energy technologies could reduce CO_2 significantly in eastern China. Moreover, Shao et al. (2021) found that green technology innovation has no significant impact on CO2 emissions in the short run, however, it has a long-run negative association with CO2 emissions in the long run.

Although there is plenty of research on green innovation and carbon dioxide emissions, there is a lack of study on the linear and non-linear relationship between green innovation and carbon dioxide emissions based on different quantiles in the G20 countries. Furthermore, previous studies have typically overlooked the sustainable ocean economy as a proxy for green innovation. In the previous literature, expenses on R&D, the global innovation index, the total number of resident and non-resident patents, and renewable energy consumption per capita (as a share of combustible renewables), (Lee and Min, 2015; Mohd Suki et al., 2022; Cetin, 2018; Tahsin, 2022). However, ignoring a sustainable ocean economy may provide biased estimates. Hence, this study intends to fill the gap by investigating the linear and non-linear relationship between green innovation and carbon dioxide emissions in the G20 countries.

2.4 Globalization, and CO_2 Emissions

The term "globalization" describes the connectivity of economies all over the world as a result of the enhancement of technology, trade openness, transactional operations of multinational companies, and transactional capital flow (Gasimli et al., 2022). The relationship between globalization and environmental quality has become a widely researched topic. Although many studies have examined the impact of globalization on CO2 emissions, there is still no consensus on the globalization-pollution nexus. Those in favour of the globalization-beneficial-environmental perspective argue that economic globalization benefits participating countries' environment quality by spreading cleaner technologies and efficient management modes among their economic activities (Gasimli et al., 2022; Rahman, 2020; Ma & Wang, 2021, Rehman et al., 2021). However, advocates of the globalization-detrimental-environmental perspective claim that globalization worsens the global environmental quality as a whole (Rahman & Alam, 2022; Xia et al., 2022; Chen et al., 2021).

The idea that globalization is a factor in the rise in carbon dioxide emissions is supported by several works of literature including Rahman & Alam (2022) for Asian countries, Xia et al., (2022) for 64 developed and developing countries, and Chen et al. (2021) for the Belt and Road countries. Conversely, several studies observed a negative relationship between globalization and CO2 (Gasimli et al., 2022; Rahman, 2020; Ma & Wang, 2021; Rehman et al., 2021). On the other hand, Ullah et al. (2022) divided the country into two groups, which are lower-globalized economies (LGE) and higher-globalized economies (HGE). They found that globalization affects CO2 negatively in HGE and positively in LGE. However, Nan et al., (2022) found that has no significant impact on CO2 in domestic countries while reducing CO2 in neighboring countries.

As mentioned above, there is no consensus on how globalization could impact environmental quality. The impact of globalization on environmental quality may be different according to various carbon dioxide emissions levels. Thus, we are going to fill the knowledge gap in this study by examining the existence of a linear relationship between globalization and CO2 and the globalization-induced EKC hypothesis in different levels of CO2 emissions countries.

2.5 Summary of Hypotheses Development

The hypothesis of the research:

H1: There is a significant positive relationship between ICT and CO2

H2: There is a significant negative relationship between green innovation and CO2

H3: There is a significant negative relationship between globalization and CO2

H4: There is an inverted U-shape relationship between ICT and CO2

H5: There is an inverted U-shape relationship between green innovation and CO2

H6: There is an inverted U-shape relationship between globalization and CO2

2.6 Research Gap

Upon conducting a literature review, we have not found any research that provides substantial evidence to validate the relationship between ICT, ICT EKC hypothesis, green innovation, and globalization with carbon dioxide emissions across various quantiles in a single study. In addition, we noticed that many studies in this area have not specifically focused on the time period of 1970 to 2019. Given that results may vary depending on the specific time period studied, there is a need for new research on this topic that focuses specifically on the period from 1970 to 2019. To fill this research gap, our paper aims to employ quantile regression techniques to validate these hypotheses and explore the potential linear and non-linear relationships between carbon dioxide emissions, information, and communication technologies, green innovation, and globalization. By focusing specifically on the time period from 1970 to 2019, our study aims to provide policymakers with detailed information that can inform their decision-making regarding countries with varying levels of carbon dioxide emissions.

2.7 Conclusions

The aim of this review was to evaluate research conducted on the causes of environmental deterioration, with a focus on analyzing the effects of Information and Communication Technologies (ICT), green innovation, and globalization, on the environment. The literature review indicates that the impacts of these variables on the environment vary depending on the specific research investigated, as diverse outcomes have been observed in different locations utilizing distinct methodologies. Given the mounting concern regarding environmental issues, this field of research is of great significance. Therefore, additional investigations are necessary to gain a more profound understanding of the relationships among these variables, which will enable policymakers to create effective policies while safeguarding the environment.

CHAPTER 3 METHODOLOGY

3.0 Introduction

This chapter details the research methodology employed in this study. Section 3.1 outlines the collected data, including variable descriptions and their sources. In section 3.2, descriptive analysis and correlation analysis of the data is presented to enhance the understanding. Section 3.3 explains the construction of the research model utilized in this study. Finally, section 3.4 concludes this chapter.

3.1 Data

This study analyses the annual data of the G20 countries from 1970 to 2019. The G20 is a group of 19 countries and the European Union which consists of Australia, Belgium, Brazil, Bulgaria, Canada, China, Cyprus, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, India, Indonesia, Ireland, Italy, Japan, Korea Republic, Latvia, Lithuania, Luxembourg, Malta, Mexico, Netherlands, Poland, Portugal, Romania, Russian Federation, Saudi Arabia, Slovak Republic, Slovenia, South Africa, Spain, Sweden, Turkiye, United Kingdom, and United States that together account for around 80% of the world's GDP, and also a significant portion of global CO2 emissions. Our study period of 1970-2019 was chosen for two main reasons. Firstly, globalization trends began in the 1950s and 1960s but gained significant traction in the 1980s and 1990s. Therefore, we chose 1970 as the starting point for our research to capture the period of significant globalization trends. Secondly, the latest annual data for most of the variables we are examining are available up to 2019, so we selected this as the end of our study period to ensure that we are utilizing the most current and comprehensive data available.

Table 3.1: Data descriptions

Variables specification	Variables	Variables Description	Source
Dependent variable	**CO2**	CO2 emissions (kt)	World Development Indicators
Independent variable	**ICTGI**	ICT goods imports (% total goods imports)	World Development Indicators
	PAR	Patent applications, residents	World Development Indicators
	KOFGI	KOF Globalisation Index	KOF Swiss Economic Institute
	ERT	Environment-related technologies (%)	OECD.Stat
	CCAT	Climate change adaptation technologies (%)	OECD.Stat
	SOE	Sustainable ocean economy (%)	OECD.Stat
Control variable	**FDII**	Foreign direct investment, net inflows (% of GDP)	World Development Indicators
	GDPC	GDP per capita (constant 2015 US$)	World Development Indicators

This research utilizes seven independent variables: ICTGI, PAR, KOFGI, ERT, CCAT, and SOE. The explanatory variables used in this study are discussed below:

1) Globalisation: The KOF Globalisation index is used in this study as a proxy of Globalisation (KOFGI). The data for this variable was collected from the KOF Swiss Economic Institute, in accordance with Ullah et al., (2022), Nan et al. (2022), Rahman & Alam (2022), Rahman (2020), Sheraz et al. (2021), Gasimli et al., 2022, and Xia et al. (2022).
2) ICT: This study follows Nguyen et al. (2020) by using the percentage of imported ICT goods over total imports as a proxy of ICT.
3) Green innovation: By referring to the previous literature, we used the variable of resident patents applications, environmental-related technologies, climate change adaptation technologies, and sustainable ocean economy to represent green innovation (Sun et al., 2019; Lee and Min, 2015; Mohd Suki et al., 2022; Cetin, 2018; Choudhary et al., 2021; Tahsin, 2022; Winther et al., 2020).
4) Control variables: Foreign direct investment, net inflows, and GDP per capita are included in this study to prevent any omitted variable.

3.2 Data Estimation

3.2.1 Descriptive Analysis

Table 3.2: Descriptive Analysis

Variable	Mean	Std. Dev.	Min	Max	Observations
CO2	542670.1	1301533	1350	11000000	N = 1260
FDII	4.729981	22.03236	-57.5323	449.083	N = 1817
GDPC	21776.44	17412.71	283.585	112418	N = 1836
ICTGI	9.652002	5.130538	3.11802	42.3667	N = 837
PAR	24934.12	96592.98	1	1400000	N = 1474
KOFGI	66.87295	15.16718	21	91	N = 1952
ERT	10.38188	6.27227	0.84	100	N = 1796
CCAT	4.768676	21.10548	0	411.99	N = 1631
SOE	3.30146	20.75778	0	603.47	N = 1363

Table 3.2 displays a summary of the variables. In total, there are 813 observations from 42 countries within 50 years. From the table above, we can observe that there are big differences between the maximum and minimum in the variables, indicating that the gap between countries is big. The huge differences in CO2 for the G20 countries are probably due to the variation in industrialization and economic development, the energy mix, the population and demographics, the climate and geographics, and government policies and regulations. Numerous factors, including changes in governmental policy, trade relations, natural disasters, global economic conditions, and technological advancements, might have an impact on GDP differences among G20 nations. Besides, the number of PAR in a country can vary for a variety of reasons, including technological advancement, economic conditions, intellectual property laws, education and research, government policies, and demographic factors. On the other hand, the 0 minimum value of CCAT and SOE revealed that some countries might not have CCAT and SOE due to the lack of resources, lack of awareness, limited technology transfer, limited capacity, and poor local conditions.

3.2.2 Correlation Analysis

Table 3.3: Correlation Analysis

	lnCO2	lnFDII	lnGDPC	lnICTGI	lnPAR	KOFGI	ERT	CCAT	SOE
lnCO2	1								
lnFDII	0.1119	1							
lnGDPC	0.3979	0.1039	1						
lnICTGI	0.6401	0.1966	0.3453	1					
lnPAR	0.6043	-0.0263	0.3629	0.4125	1				
KOFGI	0.4763	0.1513	0.5256	0.5397	0.3073	1			
ERT	-0.0076	-0.0028	-0.0279	0.0767	-0.0411	-0.0701	1		
CCAT	-0.1321	-0.0144	-0.2819	-0.1058	-0.156	-0.1922	0.1058	1	
SOE	-0.072	-0.0311	-0.3024	-0.1043	-0.119	-0.1802	0.1476	0.6291	1

Table 3.3 shows the correlation between the variables. The result reveals that lnCO2 increase along with the rise of lnFDII, lnGDPC, lnICTGI, lnPAR, and KOFGI, but decrease along with the rise of ERT, CCAT, and SOE. Overall, the KOFGI has the weakest correlation with the other variable, while lnICTGI has the highest correlation coefficient with the remaining variables. Thus, we will suggest removing the variable, ICTGI as the main independent variable in the CO2 nexus and replace with ERT or CCAT in the future study.

3.3 Model Construction

In recognition of the fact that the effects of ICT, green innovation, and globalization can vary across countries at different stages of development, our study seeks to examine the impact of these factors on carbon dioxide (CO2) emissions by modifying the specifications of prior study (Nguyen et al., 2020). To achieve our first objective, we specify the conditional quantile function for quantile τ as the Eq (1) below:

$$lnCO2_{it}(\tau/x) = f(lnICTGI_{it}, lnPAR_{it}, KOFGI_{it}, ERT_{it}, CCAT_{it}, SOE_{it}, lnFDII_{it}, lnGDPC_{it}) \tag{1}$$

$lnICTGI_{it}$ represents the imports of ICT goods, $lnPAR_{it}$ denotes the residents' patent applications, $lnKOFGI_{it}$ represents the KOF Globalization Index, ERT_{it} denotes the environment-related technologies, $CCAT_{it}$ indicates the climate change adaptation technologies, and SOE_{it} represents the sustainable ocean economy, $lnFDII_{it}$ denotes the net inflows of foreign direct investment, $lnGDPC_{it}$ represents the GDP per capita.

Eq. (2) of the study is being constructed with the aim to estimate the inverted U-shape relationship between ICT and CO2 emissions.

$$lnCO2_{it}(\tau/x) = f(lnICTGI_{it}{}^2, lnICTGI_{it}, lnPAR_{it}, KOFGI_{it}, ERT_{it}, CCAT_{it}, SOE_{it}, lnFDII_{it}, lnGDPC_{it}) \quad (2)$$

In this context, the variable lnICTGI2 represents the squared value of ICT goods imports.

Eq. (3), Eq. (4), Eq. (5), and Eq. (6) of the study are being constructed with the aim to estimate the inverted U-shape relationship between green innovation and CO2 emissions.

$$lnCO2_{it}(\tau/x) = f(lnPAR_{it}{}^2, lnPAR_{it}, lnICTGI_{it}, KOFGI_{it}, ERT_{it}, CCAT_{it}, SOE_{it}, lnFDII_{it}, lnGDPC_{it}) \quad (3)$$

In Eq. (3), $lnPAR^2$ represents the squared value of patent applications.

$$lnCO2_{it}(\tau/x) = f(ERT_{it}{}^2, ERT_{it}, lnICTGI_{it}, KOFGI_{it}, lnPAR_{it}, CCAT_{it}, SOE_{it}, lnFDII_{it}, lnGDPC_{it}) \quad (4)$$

In Eq. (4), $lnERT^2$ represents the squared value of environmental-related technologies.

$$lnCO2_{it}(\tau/x) = f(CCAT_{it}{}^2, CCAT_{it}, lnICTGI_{it}, KOFGI_{it}, lnPAR_{it}, ERT_{it}, SOE_{it}, lnFDII_{it}, lnGDPC_{it}) \quad (5)$$

In Eq. (5), $CCAT^2$ denotes the squared value of climate change adaptation technologies.

$$lnCO2_{it}(\tau/x) = f(SOE_{it}{}^2, SOE_{it}, lnICTGI_{it}, KOFGI_{it}, lnPAR_{it}, ERT_{it}, CCAT_{it}, lnFDII_{it}, lnGDPC_{it}) \quad (6)$$

In Eq. (6), SOE^2 denotes the squared value of the sustainable ocean economy.

Eq. (7) of the study is being constructed with the aim to estimate the inverted U-shape relationship between globalization and CO2 emissions.

$$lnCO2_{it}(\tau/x) = f(lnKOFGI_{it}{}^{2}, lnKOFGI_{it}, lnICTGI_{it}, lnPAR_{it}, ERT_{it}, CCAT_{it}, SOE_{it}, lnFDII_{it}, lnGDPC_{it}) \quad (7)$$

In Eq. (7), the $KOFGI^2$ represents the squared value of the KOF Globalization Index.

3.4 Conclusion

This chapter commences with a clear description of the data used in the study. Subsequently, descriptive and correlation analyses of the data are performed to facilitate a better understanding of it. Later in the chapter, the construction of the research model, which comprises seven equations examining the linear and non-linear relationship between various variables and carbon dioxide emissions is discussed. Finally, the chapter concludes by discussing the utilization of Quantile Regression in conducting the study.

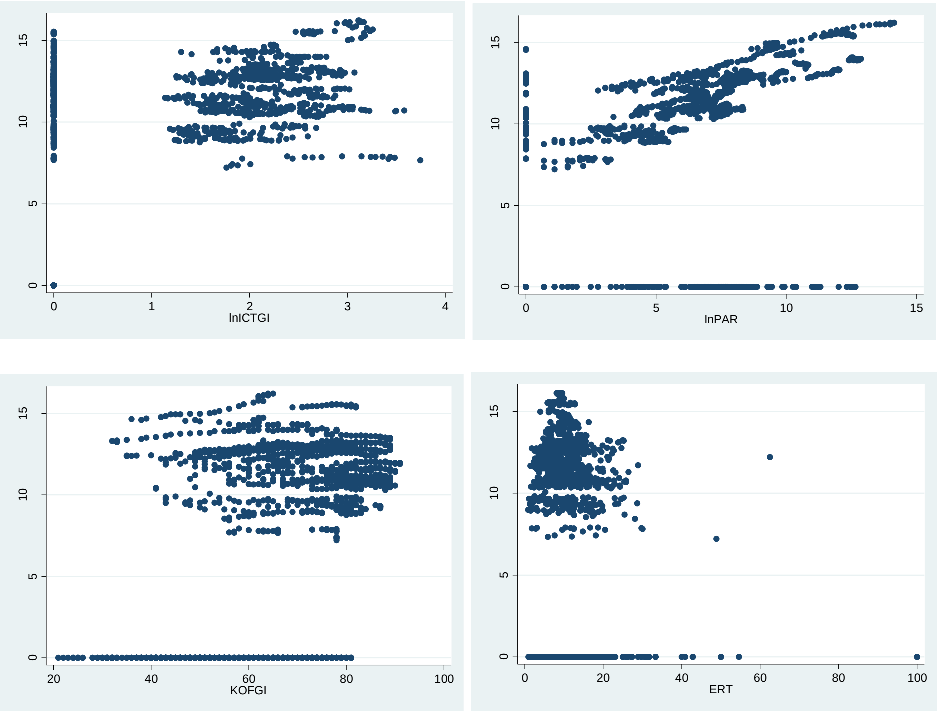
CHAPTER 4 EMPIRICAL RESULTS AND DISCUSSION

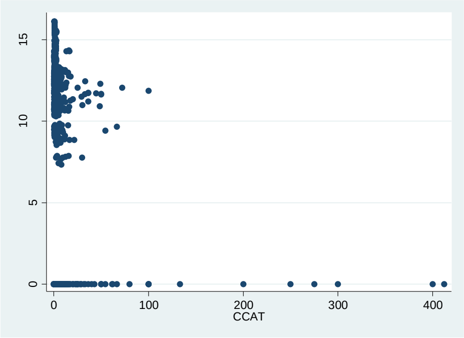
4.0 Introduction

In this chapter, the outcomes obtained from running the data through the research model mentioned in Chapter 3 will be explained. In section 4.1, residual plots and OLS results will be conducted as additional tests to support the quantile regression. In Section 4.2, the results of the economic growth-induced EKC hypothesis will be discussed, followed by a review of the globalization-induced EKC hypothesis in section 4.2. The results of the financial-development-induced EKC hypothesis will be examined in section 4.3, and the findings of the tourism-induced EKC hypothesis will be discussed in section 4.4. Lastly, the overall findings of this research will be concluded in section 4.5.

4.1 Residual Plots and OLS Result

Figure 4.1. The residual plots for independent variables





Source: Developed for research

As shown in Figure 4.1, the residual plots for all the independent variables are not constant. Thus, it is suggested to use quantile regression to investigate the relationship between the variables.

Table 4.1: OLS Result

Variable	OLS pooled	RE Estimator	FE Estimator
lnICTGI	0.933*** (3.75）	0.45 (1.59)	0.629* (2.26）
lnPAR	0.593*** (18.58）	0.554*** (16.85)	0.643*** (19.3）
KOFGI	0.028*** (2.57）	0.386*** (18.76)	0.146*** (9.2）
ERT	0.02 (0.67）	-0.071** (-2.60)	(0.01) (-0.32）
CCAT	0.02 (0.60）	0.02 (0.89)	0.02 (0.56）
SOE	0.092*** (3.31）	0.127*** (5.19)	0.102*** (3.87）
lnFDII	2.399** (2.72）	1.24 (1.55)	1.767* (2.08）
lnGDPC	0.08 (1.31）	0.178** (2.63)	0.12 (1.68）

Notes: The symbols (*), (**), (***) denote statistical significance at 10%, 5% and 1% level, respectively whereas t-statistics are reported in brackets.

Generally, the OLS result showed that PAR, KOFGI, and SOE are the most significant variable that affected the carbon dioxide emissions (CO2) in all estimators. ICTGI is only significant with CO2 emissions in terms of OLS pooled regression. The inconsistency of results across different estimators can be attributed to potential inaccuracies in the estimation process. Given that variables may have varying impacts on CO2 emissions in different countries, we decided to employ quantile regression in the subsequent analysis to explore these potential differences.

4.2 Results and Discussion of the Quantile Regression

4.2.1 Linear relationship

Figure 4.2: Quantile Regression diagram without a 95% confidence interval

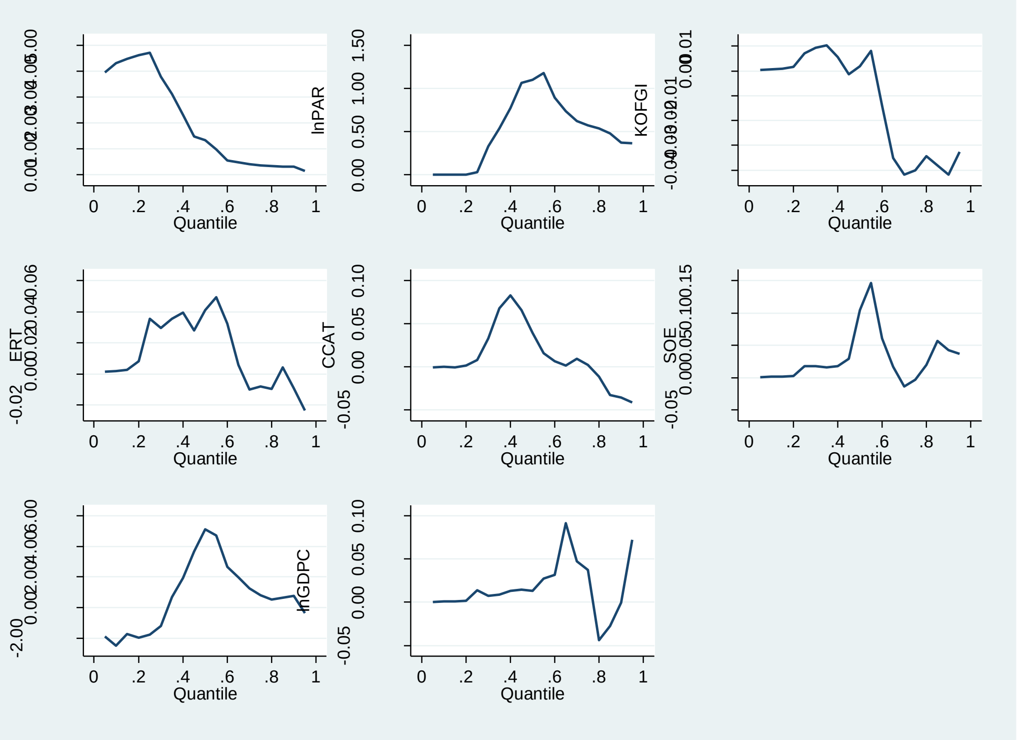


Figure 4.3: Quantile Regression diagram with 95% confidence interval

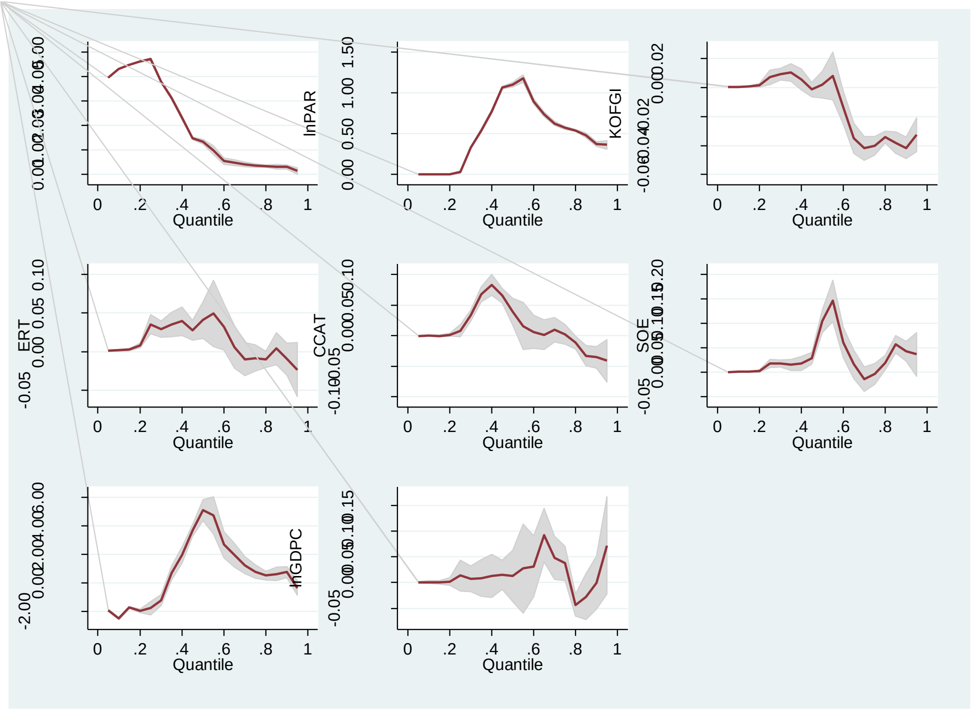


Table 4.2: Results of Eq.(1)

Variables	Q10	Q20	Q30	Q40	Q50	Q60	Q70	Q80	Q90
lnICTGI	2.004***	2.297***	2.573***	0.944*	0.303	-0.0508	-0.0865	0.111	0.262
	(26.22)	(22.09)	(5.82)	(2.08)	(0.65)	(-0.12)	(-0.48)	(0.74)	(1.65)
lnPAR	0.00199	0.000103	0.168**	0.687***	1.088***	0.799***	0.619***	0.546***	0.369***
	(0.20)	(0.01)	(2.97)	(11.82)	(18.15)	(15.27)	(26.97)	(28.36)	(18.19)
KOFGI	0.00108	0.0000428	0.0115	0.0245	-0.000977	-0.0159	-0.0402***	-0.0449***	-0.0398***
	(0.32)	(0.01)	(0.59)	(1.22)	(-0.05)	(-0.88)	(-5.09)	(-6.77)	(-5.70)
ERT	0.00598	0.000199	0.0482	0.0547	0.038	-0.00712	-0.0176	-0.00588	-0.0104
	(0.68)	(0.02)	(0.95)	(1.05)	(0.71)	(-0.15)	(-0.86)	(-0.34)	(-0.57)
CCAT	0.00883	0.000141	0.0459	0.114*	0.0924	0.0122	-0.0151	-0.0106	-0.0326
	(1.08)	(0.01)	(0.97)	(2.33)	(1.84)	(0.28)	(-0.79)	(-0.65)	(-1.92)
SOE	-0.0162	-0.000154	-0.0105	0.0242	0.0117	0.0422	0.031	0.0081	0.0437*
	(-1.89)	(-0.01)	(-0.21)	(0.48)	(0.22)	(0.92)	(1.55)	(0.48)	(2.46)
lnFDII	-1.464***	-0.0436	-0.392	1.112	2.226	0.952	1.074	0.84	0.825
	(-5.40)	(-0.12)	(-0.25)	(0.69)	(1.34)	(0.66)	(1.69)	(1.57)	(1.47)
lnGDPC	0.00106	0.0000414	0.0256	0.0212	0.0102	0.0544	0.112*	0.0205	-0.00184
	(0.06)	(0.00)	(0.24)	(0.19)	(0.09)	(0.55)	(2.57)	(0.56)	(-0.05)
Constant	5.801***	0.172	0.106	-6.725	-9.346	1.572	4.569	7.769***	9.628***
	(5.19)	(0.11)	(0.02)	(-1.01)	(-1.37)	(0.26)	(1.74)	(3.53)	(4.16)

Notes: The symbols (*), (**), (***) denote statistical significance at 10%, 5% and 1% level, respectively whereas t-statistics are reported in brackets.

In Table 4.1, the effects of independent variables on nine different quantiles of dependent variables, the CO2 was demonstrated. The findings of the study suggest that the quantile effect appears in all independent variables, ICTGI, PAR, ERT, KOFGI, FDII, and GDPC.

Regarding Information Communication Technologies, results provide evidence that ICT has a significant positive effect in lower quantiles (10th to 40th) but has no significant impact on CO2 emissions in higher quantiles (50th to 90th). This result has revealed that ICT has exacerbated environmental degradation in lower CO2 countries. Similar results have also been found by Park et al. (2018), Asongu et al. (2018), Avom et al. (2020), Tsaurai & Chimbo (2019), Arshad et al. (2020), and Raheem et al. (2020). To sum up, the findings rejected Hypothesis 1.

With respect to PAR, the results show that patents application effects on CO2 emissions are positively significant at the 30th to 90th quantile. It means that the application of patents degrades the environmental quality for the majority of G-20 countries. This result opposes the findings of the previous study by Gibbins, and Lucquiaud (2016), Tahsin (2022), and Khan et al. (2021). ERT and CCAT are positively related to CO2 at lower quantiles and negatively related to CO2 at higher quantiles, while the effect of SOE on CO2 emissions at the lower CO2 emissions, which is the 10th to 30th quantile countries is negative. However, the impact of these variables (ERT, CCAT, and SOE) are not significant. According to Intergovernmental Panel on Climate Change (2018), adaptation involves making modifications to cope with the current or anticipated climate conditions and their consequences. Within human systems, the aim of adaptation is to mitigate or prevent adverse impacts while taking advantage of advantageous opportunities. In certain natural systems, human involvement may facilitate adaptation to anticipated climate changes and their effects (Cradock-Henry et al., 2019). Therefore, the deduction can be made that either human or technological intervention alone may not be sufficient to mitigate the climate change problem and prevent environmental deterioration, or the CCAT may not effectively reduce carbon dioxide emissions. Subsequently, the technologies related to the environment, as defined in our context, encompass the overall management of environmental concerns. Therefore, the outcome indicates that this general environmental management does not have a noteworthy effect on restraining environmental deterioration. According to the OECD (2016), the ocean economy encompasses the economic activities of industries based in the ocean, as well as the assets, goods, and services that marine ecosystems provide. Hence, the insignificant result of SOE may imply that the ocean economy is not much associated with carbon dioxide emissions. In regards to green innovation, the patent applications rejected Hypothesis 2, while the other indicators, ERT, CCAT, and SOE are not significant.

As seen in the table above, the KOFGI coefficients are negative for the 50th to 90th quantiles, but the effects are only significant at the higher quantiles (70th to 90th). The results denoted that globalization reduces environmental pollution in the high CO2 emissions countries. This is supported by Gasimli et al. (2022), Rahman (2020), Ma & Wang (2021), and Rehman et al. (2021) who claimed that globalization reduces CO2 emissions. Therefore, the alternative hypothesis of Hypothesis 3 is rejected for the high carbon dioxide emissions countries.

At the majority quantiles, FDII and GDPC have no significant effect on carbon dioxide emissions. Foreign direct investment (FDII) is only significant at 1% on the 10th quantile and the results are negative. This shows that the FDII could decrease the carbon dioxide emissions in the lowest carbon dioxide emissions countries. On the other hand, the GDP per capita (GDPC) is only positively significant at 10% on the 70th quantile. This may be due to the fact that an increase in GDP leads to increased economic activities, resulting in higher carbon dioxide emissions.

4.2.2 ICT-Induced EKC Hypothesis

Table 4.3: Results of Eq.(2)

Variable	**Q10**	**Q20**	**Q30**	**Q40**	**Q50**	**Q60**	**Q70**	**Q80**	**Q90**
lnICTGI	8.782***	8.479***	8.667***	6.307***	4.670**	1.053	0.462	-0.441	-0.448
	(48.98)	(42.35)	(10.78)	(7.67)	(3.50)	(0.90)	(3.09)	(-1.10)	(-1.20)
lnICTGI^2	-1.917***	-1.799***	-1.894***	-1.465***	-1.165**	-0.339	-0.185	0.186	0.247*
	(-36.86)	(-30.98)	(-8.12)	(-6.14)	(-3.01)	(-0.92)	(-1.25)	(1.59)	(2.28)
lnPAR	0.001	0.007	0.129**	0.536***	0.824***	0.790***	0.645***	0.523***	0.388***
	(0.17)	(0.68)	(3.26)	(13.25)	(12.56)	(12.65)	(25.66)	(26.42)	(21.17)
KOFGI	0.0000569	-0.00165	0.0145	0.00509	-0.00802	-0.0281	-0.0458***	-0.0301***	-0.0398***
	(-0.02)	(-0.47)	(-1.02)	(-0.35)	(-0.34)	(-1.26)	(-5.10)	(-4.25)	(-5.93)
ERT	-0.00274	-0.00806	-0.0439	-0.0352	-0.0208	-0.0160	-0.0149	-0.00652	0.00275
	(-0.34)	(-0.89)	(-1.20)	(-0.94)	(-0.34)	(-0.28)	(-0.64)	(-0.36)	(0.16)
CCAT	0.00529	0.00776	0.0282	0.0603	0.101	0.00545	-0.00876	-0.0121	-0.0354*
	(0.72)	(0.95)	(0.86)	(1.79)	(1.86)	(0.10)	(-0.42)	(-0.74)	(-2.32)
SOE	-0.0195*	-0.0164	-0.0408	-0.0103	0.0206	0.0552	0.0116	0.0301	0.0459**
	(-2.54)	(-1.92)	(-1.19)	(-0.29)	(0.36)	(1.02)	(0.53)	(1.75)	(2.88)
lnFDII	-0.557*	-0.768**	-0.792	0.537	1.710	1.252	1.141	0.673	0.884
	(-2.29)	(-2.83)	(-0.73)	(0.48)	(0.95)	(0.73)	(1.65)	(1.23)	(1.75)
lnGDPC	-0.000621	0.000199	0.0658	0.00450	0.00975	0.119	0.127**	-0.0460	-0.00637
	(-0.04)	(0.01)	(0.88)	(0.06)	(0.08)	(1.01)	(2.69)	(-1.24)	(-0.18)
Constant	2.285*	3.261**	3.716	-1.680	-6.388	0.402	4.278	8.211***	9.062***
	(2.28)	(2.92)	(0.83)	(-0.37)	(-0.86)	(0.06)	(1.50)	(3.65)	(4.36)

Notes: The symbols (*), (**), (***) denote statistical significance at 10%, 5% and 1% level, respectively whereas t-statistics are reported in brackets.

Table 4.2 shows the results of the non-linear relationship between ICT and CO2 emissions on the ICT-induced EKC hypothesis. Looking at the table alone, it can be observed that ICT has a significant impact on CO2 emissions for the 10th to 50th quantiles and has no significant effect on the 60th to 90th quantiles. In the results, the coefficients of ICTGI are in positive form, while the coefficients of ICTGI^2 are in negative form. This result implies that ICT is having an inverted U-shape relationship with the CO2 emissions for the low to middle CO2 emissions countries. The U-shape relationship proposed that the ICT increases carbon dioxide at the early stage, and enhances the environmental quality at the later stage. It infers that lower CO2 emissions countries could potentially lower their CO2 emissions further by leveraging further advancements in ICT. This result has also been validated by Añón Higón et al. (2017) and Faisal et al. (2020) in their study.

To sum up, the findings in this section fully support Hypothesis 4 since the inverted U-shape is found in the relationship between ICT and CO2 emissions.

4.2.3 Green Innovation-Induced EKC Hypothesis (PAR, ERT, CCAT, SOE)

Table 4.4: Results of Eq.(3)

Variable	Q10	Q20	Q30	Q40	Q50	Q60	Q70	Q80	Q90
lnPAR	-0.0058	-0.0268	-0.0050	1.9619***	2.1518***	2.2079***	2.2293***	0.5430	-0.0289
	(0.0071)	(0.0575)	(0.2970)	(0.1901)	(0.0366)	(0.0514)	(0.1444)	(0.4175)	(0.0984)
lnPAR^2	0.0009	0.0037	0.0128	-0.0805***	-0.0911***	-0.0940***	-0.0948***	0.0003	0.0306***
	(0.0008)	(0.0078)	(0.0132)	(0.0102)	(0.0026)	(0.0035)	(0.0085)	(0.0227)	(0.0067)
lnICTGI	2.0029***	2.3144***	2.6117***	0.1444	0.0121	0.0916	0.2482	0.1111	-0.0261
	(0.2220)	(0.1727)	(0.4536)	(0.2463)	(0.0892)	(0.1598)	(0.1588)	(0.0942)	(0.0657)
KOFGI	0.0019	0.0017	0.0184*	-0.0013	-0.0127***	-0.0289***	-0.0472***	-0.0447***	-0.0443***
	(0.0012)	(0.0044)	(0.0107)	(0.0017)	(0.0042)	(0.0082)	(0.0087)	(0.0148)	(0.0071)
ERT	0.0077*	0.0068	0.0691***	-0.0031	-0.0089	-0.0114	-0.0085	-0.0061	0.0058
	(0.0043)	(0.0128)	(0.0197)	(0.0079)	(0.0075)	(0.0119)	(0.0178)	(0.0154)	(0.0062)
CCAT	0.0101**	0.0048	0.0517	0.0171	0.0130	-0.0025	0.0010	-0.0105	-0.0146
	(0.0047)	(0.0260)	(0.0364)	(0.0218)	(0.0165)	(0.0180)	(0.0299)	(0.0158)	(0.0164)
SOE	-0.0162**	-0.0044	-0.0098	-0.0013	0.0036	0.0272	0.0278	0.0083	0.0296
	(0.0068)	(0.0132)	(0.0445)	(0.0201)	(0.0422)	(0.0534)	(0.0641)	(0.0495)	(0.0277)
lnFDII	-1.4795*	-0.2060	-0.3846	0.6898	0.8566	2.6916***	3.2601***	0.8395	0.1742
	(0.8115)	(1.0421)	(0.6255)	(0.5916)	(0.7859)	(0.9743)	(1.1644)	(0.9164)	(0.3753)
lnGDPC	-0.0007	0.0007	0.0245	0.0025	0.0167*	0.0324	0.0636	0.0200	-0.0275
	(0.0017)	(0.0034)	(0.0736)	(0.0063)	(0.0093)	(0.0335)	(0.0641)	(0.1624)	(0.0602)
Constant	5.8065*	0.6504	-0.5536	-2.7345	-2.6846	-8.9997**	-10.1093**	7.7768	13.6771***
	(3.2483)	(4.1692)	(2.6119)	(2.4564)	(3.2218)	(3.8558)	(4.6033)	(5.0452)	(1.7361)

Notes: The symbols (*), (**), (***) denote statistical significance at 10%, 5% and 1% level, respectively whereas t-statistics are reported in brackets.

Table 4.3 revealed the results of the non-linear relationship between PAR and CO2 across different CO2 levels. Both PAR and PAR^2 s' coefficients are significant at 1% level for Q40 to Q70. The results indicate that there is an inverted U-shaped relationship between carbon dioxide and patent applications, as evidenced by the significantly positive coefficients of PAR and significantly negative coefficients of PAR2 across the 40th to 70th quantiles. The relationship would suggest that initially, as patent applications increase, carbon dioxide emissions may also increase due to increased innovation and industrial activity. However, beyond a certain point, further increases in patent applications may lead to decreased carbon dioxide emissions, as innovative technologies and processes are developed to improve efficiency and reduce environmental impact.

Table 4.5: Results of Eq.(4)

Variables	Q10	Q20	Q30	Q40	Q50	Q60	Q70	Q80	Q90
ERT^2	0.0005	0.0025	0.0021	0.0022	0.0050	0.0037	0.0045	0.0014	0.0018
	(0.0013)	(0.0021)	(0.0025)	(0.0032)	(0.0041)	(0.0034)	(0.0027)	(0.0019)	(0.0023)
ERT	-0.0073	-0.0354	-0.0161	0.0020	-0.0739	-0.0890	-0.1144*	-0.0384	-0.0616
	(0.0194)	(0.0356)	(0.0596)	(0.0709)	(0.0963)	(0.0851)	(0.0650)	(0.0467)	(0.0736)
lnICTGI	1.9763***	2.3541***	2.6095***	0.9934***	0.3824	-0.0293	-0.0626	0.1090	0.2677***
	(0.2094)	(0.1547)	(0.4602)	(0.2571)	(0.2724)	(0.1660)	(0.1183)	(0.0837)	(0.0915)
KOFGI	0.0009	0.0011	0.0043	0.0214	0.0001	-0.0142	-0.0396***	-0.0446***	-0.0388***
	(0.0011)	(0.0014)	(0.0100)	(0.0153)	(0.0163)	(0.0259)	(0.0121)	(0.0125)	(0.0108)
lnPAR	0.0014	0.0025	0.1649	0.6854***	1.0945***	0.8093***	0.6184***	0.5497***	0.3864***
	(0.0017)	(0.0037)	(0.1570)	(0.0972)	(0.1007)	(0.1674)	(0.0625)	(0.0460)	(0.0413)
CCAT	0.0069*	0.0088	0.0282	0.1049**	0.0894***	0.0160	-0.0082	-0.0090	-0.0288
	(0.0037)	(0.0082)	(0.0401)	(0.0434)	(0.0333)	(0.0343)	(0.0295)	(0.0217)	(0.0194)
SOE	-0.0170**	-0.0207*	-0.0121	0.0149	0.0104	0.0460	0.0067	0.0103	0.0461
	(0.0082)	(0.0109)	(0.0460)	(0.0629)	(0.0742)	(0.0651)	(0.0571)	(0.0505)	(0.0392)
lnFDII	-1.4274**	-0.2888	-0.4253	1.2241*	2.2373**	0.9654	0.7979*	0.7575	0.7958
	(0.6102)	(0.8977)	(0.7023)	(0.6443)	(0.9214)	(0.8182)	(0.4172)	(0.6378)	(0.6710)
lnGDPC	0.0004	0.0011	0.0195	0.0181	0.0079	0.0586	0.1104	0.0173	-0.0097
	(0.0008)	(0.0026)	(0.0674)	(0.0132)	(0.1321)	(0.1893)	(0.1141)	(0.1247)	(0.0876)
Constant	5.7560**	1.1932	1.2015	-6.7015***	-8.9523**	1.6168	6.1459***	8.2387***	9.8937***
	(2.4564)	(3.6294)	(3.1181)	(2.1908)	(3.9409)	(5.5402)	(2.1617)	(2.8917)	(3.1912)

Notes: The symbols (*), (**), (***) denote statistical significance at 10%, 5% and 1% level, respectively whereas t-statistics are reported in brackets.

Results in Table 4.4 shows that the ERT has no inverted U-shape relationship with CO2. Both ERT and ERT^2 coefficients are not significant at all quantiles, except for ERT at the Q70.

Table 4.6: Results of Eq.(5)

Variables	Q10	Q20	Q30	Q40	Q50	Q60	Q70	Q80	Q90
CCAT	0.0053	0.0002	0.0281	0.1667***	0.1631*	0.0869	0.0457	0.0215	-0.0229
	(0.0082)	(0.0180)	(0.0487)	(0.0611)	(0.0840)	(0.0966)	(0.0681)	(0.0579)	(0.0308)
CCAT^2	0.0001	-0.0000	0.0009	-0.0013	-0.0024	-0.0019	-0.0010	-0.0009	-0.0003
	(0.0003)	(0.0010)	(0.0018)	(0.0027)	(0.0036)	(0.0036)	(0.0022)	(0.0019)	(0.0007)

lnICTGI	1.9925***	2.2973***	2.6016***	0.8924**	0.3351	-0.0977	-0.0496	0.1095	0.2572***
	(0.2152)	(0.2216)	(0.4302)	(0.4074)	(0.2200)	(0.1536)	(0.1059)	(0.0725)	(0.0872)
KOFGI	0.0007	0.0000	0.0099	0.0301***	0.0010	-0.0076	-0.0378**	-0.0423***	-0.0392***
	(0.0014)	(0.0034)	(0.0071)	(0.0111)	(0.0123)	(0.0216)	(0.0156)	(0.0143)	(0.0120)
lnPAR	0.0013	0.0001	0.1591	0.6890***	1.0889***	0.9049***	0.6351***	0.5565***	0.3695***
	(0.0032)	(0.0071)	(0.1410)	(0.1034)	(0.0789)	(0.1742)	(0.0578)	(0.0370)	(0.0391)
ERT	0.0044	0.0002	0.0495**	0.0481***	0.0247	-0.0017	-0.0293	-0.0186	-0.0104
	(0.0067)	(0.0130)	(0.0201)	(0.0074)	(0.0204)	(0.0244)	(0.0214)	(0.0188)	(0.0171)
SOE	-0.0165	-0.0002	-0.0159	0.0447	0.1101	0.1206*	0.0702	0.0674	0.0438
	(0.0100)	(0.0130)	(0.0427)	(0.0589)	(0.0853)	(0.0639)	(0.0570)	(0.0515)	(0.0470)
lnFDII	-1.4445**	-0.0438	-0.3742	1.0269*	2.1662***	1.1061	0.7601	0.8758	0.8314
	(0.7219)	(0.9721)	(0.7902)	(0.5605)	(0.7943)	(1.1138)	(0.5806)	(0.7800)	(0.8860)
lnGDPC	0.0009	0.0000	0.0224	0.0212*	0.0127	-0.0138	0.0972	0.0211	-0.0037
	(0.0008)	(0.0030)	(0.0743)	(0.0110)	(0.0602)	(0.2068)	(0.1734)	(0.1517)	(0.1180)
Constant	5.7696**	0.1723	0.2013	-6.7826***	-9.2119***	-0.1293	5.6575**	7.3500**	9.5631**
	(2.9026)	(3.8248)	(3.9177)	(2.2844)	(3.3568)	(6.1209)	(2.7850)	(3.3761)	(3.8643)

Notes: The symbols (*), (**), (***) denote statistical significance at 10%, 5% and 1% level, respectively whereas t-statistics are reported in brackets.

According to the results presented in Table 4.5, CCAT and CO2 does not have a non-linear relationship. The coefficients of both CCAT and CCAT2 were found to be insignificant at all quantiles, except for CCAT which showed significance only at the 40th and 50th quantiles.

Table 4.7: Results of Eq.(6)

Variables	Q10	Q20	Q30	Q40	Q50	Q60	Q70	Q80	Q90
SOE	0.0026	0.0011	-0.0337	0.0700	0.1708**	0.0919	-0.0023	-0.0524	-0.0200
	(0.0154)	(0.0166)	(0.0560)	(0.0736)	(0.0800)	(0.0863)	(0.0458)	(0.0428)	(0.0642)
SOE^2	-0.0003	-0.0002	0.0015	-0.0011	-0.0023	-0.0015	0.0010	0.0014	0.0007
	(0.0010)	(0.0012)	(0.0013)	(0.0016)	(0.0017)	(0.0014)	(0.0014)	(0.0012)	(0.0015)
lnICTGI	1.9839***	2.3384***	2.5817***	0.9187**	0.4254	-0.1024	-0.0843	0.0864	0.2441**
	(0.1391)	(0.1781)	(0.4803)	(0.4348)	(0.3044)	(0.2092)	(0.1138)	(0.0679)	(0.1092)
KOFGI	0.0008	0.0012	0.0108	0.0303**	-0.0001	-0.0139	-0.0423***	-0.0493***	-0.0409***
	(0.0005)	(0.0022)	(0.0086)	(0.0123)	(0.0132)	(0.0208)	(0.0140)	(0.0130)	(0.0117)
lnPAR	0.0016*	0.0018	0.1658	0.6827***	1.0906***	0.8288***	0.6174***	0.5361***	0.3589***
	(0.0009)	(0.0036)	(0.1592)	(0.1206)	(0.1094)	(0.1924)	(0.0602)	(0.0434)	(0.0457)
ERT	0.0027	0.0055	0.0524***	0.0483***	0.0191	-0.0031	-0.0140	-0.0024	-0.0037
	(0.0025)	(0.0064)	(0.0189)	(0.0136)	(0.0160)	(0.0197)	(0.0149)	(0.0111)	(0.0190)
CCAT	0.0017	0.0036	0.0463	0.1069***	0.0365	0.0213	-0.0074	-0.0041	-0.0181
	(0.0049)	(0.0179)	(0.0418)	(0.0406)	(0.0312)	(0.0218)	(0.0253)	(0.0158)	(0.0196)
lnFDII	-1.4307**	-0.2952	-0.3860	0.9462	2.2404***	0.9827	1.1116***	1.0417	0.7866
	(0.6624)	(0.7518)	(0.7649)	(0.6867)	(0.7640)	(1.0754)	(0.3734)	(0.8794)	(0.8672)
lnGDPC	0.0002	0.0008	0.0255	0.0199	0.0141	0.0149	0.1185	0.0457	-0.0006
	(0.0006)	(0.0025)	(0.0188)	(0.0175)	(0.1075)	(0.2622)	(0.1986)	(0.1617)	(0.1207)

Constant	5.7209**	1.0536	0.1137	-6.3792**	-9.3778***	1.3412	4.5238***	7.1092**	9.9054***
	(2.6590)	(3.0669)	(3.5225)	(2.8571)	(2.7413)	(6.3055)	(1.3546)	(3.4360)	(3.7338)

Notes: The symbols (*), (**), (***) denote statistical significance at 10%, 5% and 1% level, respectively whereas t-statistics are reported in brackets.

The results presented in Table 4.6 indicate that there is no non-linear relationship between the CCAT and CO2. With the exception of CCAT at the 40th and 50th quantiles, all coefficients of CCAT and CCAT2 were insignificant across all quantiles.

4.2.4 Globalization-Induced EKC Hypothesis

Table 4.8: Results of Eq.(7)

Variables	Q10	Q20	Q30	Q40	Q50	Q60	Q70	Q80	Q90
KOFGI	-0.0064**	-0.0007	-0.0227	-0.0465*	0.1026	0.3979***	0.1107**	0.0804**	0.0894
	(0.0031)	(0.0078)	(0.0575)	(0.0272)	(0.1040)	(0.0943)	(0.0515)	(0.0355)	(0.0615)
KOFGI^2	0.0001**	0.0000	0.0003	0.0006**	-0.0008	-0.0029***	-0.0011***	-0.0009***	-0.0010**
	(0.0000)	(0.0001)	(0.0004)	(0.0002)	(0.0007)	(0.0006)	(0.0003)	(0.0002)	(0.0004)
lnICTGI	2.0105***	2.3429***	2.5531***	0.8123***	0.4846***	0.0200	-0.0948	0.0932	0.3275**
	(0.1677)	(0.1478)	(0.4054)	(0.1710)	(0.1790)	(0.1431)	(0.1242)	(0.0746)	(0.1355)
lnPAR	0.0028**	0.0003	0.1682	0.6828***	1.0736***	0.8525***	0.6264***	0.5363***	0.3652***
	(0.0014)	(0.0044)	(0.1222)	(0.0615)	(0.0856)	(0.1093)	(0.0532)	(0.0373)	(0.0500)
ERT	0.0066	0.0006	0.0478***	0.0453***	0.0415*	0.0089	-0.0069	-0.0105	-0.0199
	(0.0047)	(0.0124)	(0.0174)	(0.0133)	(0.0217)	(0.0190)	(0.0143)	(0.0108)	(0.0131)
CCAT	0.0073	0.0004	0.0508	0.1231***	0.0837**	0.0090	-0.0118	-0.0109	-0.0411*
	(0.0046)	(0.0183)	(0.0443)	(0.0450)	(0.0353)	(0.0402)	(0.0239)	(0.0245)	(0.0214)
SOE	-0.0157	-0.0005	-0.0202	-0.0055	0.0288	0.0686	0.0201	0.0010	0.0454
	(0.0096)	(0.0128)	(0.0644)	(0.0705)	(0.0873)	(0.0904)	(0.0639)	(0.0542)	(0.0390)
lnFDII	-1.4556*	-0.0999	-0.4836	0.9577*	2.1576**	2.0476***	1.1743***	0.6812	0.5575
	(0.7668)	(0.9167)	(0.7175)	(0.5160)	(0.8880)	(0.5023)	(0.4295)	(0.5048)	(0.6818)
lnGDPC	0.0007	0.0000	0.0343	0.0180	0.0167	0.0907	0.1273	0.0103	0.0115
	(0.0009)	(0.0023)	(0.0751)	(0.0243)	(0.1861)	(0.2538)	(0.1756)	(0.1080)	(0.0818)
Constant	5.9793*	0.4138	1.5535	-3.7951	-12.3582**	-18.2520***	-1.1701	4.2401**	6.6552**
	(3.1616)	(3.8409)	(3.8105)	(2.5506)	(5.1447)	(3.7562)	(3.1717)	(2.1238)	(2.6275)

Notes: The symbols (*), (**), (***) denote statistical significance at 10%, 5%, and 1% levels, respectively whereas t-statistics are reported in brackets.

Table 4.7 shows the results of the non-linear relationship between KOFGI and CO2. All quantiles for both KOFGI and KOFGI^2 showed significant results except for the 20th, 30th, and 50th quantiles and KOFGI for the 90th quantile. In the results of the 10th and 40th quantiles, the coefficients of KOFGI are in negative form, while the coefficients of KOFGI^2 are in positive form, hence implying that globalization and carbon dioxide emissions is having a U-shape relationship. The U-shaped relationship suggests that globalization initially leads to reduces carbon dioxide emissions, but at later stages of development, it can encourage a more carbon dioxide emission lifestyle at the later stages.

In the results of the 60th to 80th quantiles, the coefficients KOFGI are in positive form, while the coefficients of KOFGI^2 are in negative form, this means that globalization is having an inverted U-shape relationship with carbon dioxide emissions. This means that initially, as a country becomes more globalized, its carbon dioxide emissions may increase as a result of increased economic activity and energy consumption. However, beyond a certain point, further globalization may lead to reduced carbon dioxide emissions, as countries become more efficient in their use of resources and more focused on sustainability.

CHAPTER 5 IMPLICATIONS AND CONCLUSION

5.0 Introduction

In this chapter, everything that has been done in this research will be concluded. The implications provided by this research will be discussed in Section 5.2. Then, the limitations faced while conducting this study will be addressed in Section 5.3, followed by recommendations for future study in Section 5.4.

5.1 Conclusion

After COP21, nations pledged to work together to address climate change. Despite the United States' withdrawal from the Paris Agreement, other significant regions such as the European Union and China continue to enhance their international cooperation efforts to address climate change concerns. Given the public's awareness of these issues and their consequences, this research examines the factors that contribute to carbon emissions in selected G20 countries between 1970 and 2019. The focus of this study is specifically on how environmental deterioration is impacted by ICT and innovation, particularly in the digital age, also referred to as the Fourth Industrial Revolution. The research is motivated by the inadequacies in existing literature concerning the effects of information and communication technologies, green innovation, and globalization on environmental degradation, as well as insufficient research in G-20 countries.

This research reveals that there are significant statistical connections between CO2 emissions and ICT, green innovation, and globalization at different quantiles. In this study, variety of theoretical frameworks are used to analyze the complex relationship between information and communication technology (ICT), green innovation, globalization, and environmental impact. These frameworks included the Use Effect, Substitution Effect, Cost Effect, and Environmental Kuznets Curve (EKC) hypothesis for ICT, Porter Hypothesis for green innovation, the income effect, the technique effect, and the composition effect for globalization.

According to the results, ICT and CO2 has a significant positive relationship between ICT and CO2 in countries that fall in the 10th to 40th and an inverted U-shaped relationship in countries that fall in the 10th to 50th quantiles of carbon dioxide emissions. In the early stages of ICT development, the use effect and the cost effect were likely to come into force, where the consumption of ICT for economic activities increased to enhance productivity and save production costs. For example, the use of cloud computing, video conferencing, data storages. While these ICT tools can reduce the needs of travel and commuting, it would require a large amount of energy to power their data centers, high speed of internets connections and use a lot of bandwidth, which can increase the emissions of carbon dioxide. As development reached a certain point, the substitution effects may have taken effect, resulting in a reduction in CO2 emissions. This implies that newer technologies, such as renewable energy technologies, may help reduce carbon emissions resulting from various economic activities.

Regarding green innovation, a significant positive relationship between patents application and CO2 was observed among countries falling within the 30th to 70th quantiles of carbon dioxide emissions. Additionally, for countries within the 40th to 70th quantiles of carbon emissions, an inverted U-shaped relationship between patent applications and carbon dioxide emissions was identified. This may imply that the compliance cost effect of the Porter Hypothesis occurs during the early stage of patent applications, while the innovation offset effect is present in the later stage of patent applications. In the early stages of a company, the costs associated with complying with environmental regulations may be a burden, particularly when most companies are striving to expand their business. Hence, the patent applied is probably not environmental-friendly, as those environmentally friendly patents would incur a higher cost. Once companies reach a particular stage of growth, they may possess sufficient skills and revenue to allocate toward environmentally-friendly technologies and practices. This could help them offset the expenses associated with complying with environmental regulations. Hence, green innovation in terms of patent applications validated the EKC hypothesis in this study.

Next, globalization and CO2 were found to have a significant negative relationship at quantiles 70th to 90th, an inverted U-shape relationship at quantiles 60th to 80th and a U-shape relationship at quantiles 10th to 40th. By just looking at the direct relationship alone, this study found that globalization could mitigate CO2 emissions for high carbon emissions countries. Incorporating the EKC hypothesis into consideration, the non-linear relationship which are inverted U-shape relationship and U-shape relationship has been found by this study. The inverted U-Shape relationship between globalization and carbon dioxide emissions in the high carbon emissions countries probably suggests that the initial increase in carbon dioxide emissions occurs as globalization leads to an increase in economic activity such as trade and manufacturing which would raise energy consumption. However, as a country becomes more developed and begins to shift towards a service-based economy, it may start to reduce its reliance on energy-intensive manufacturing and production, leading to a decline in carbon dioxide emissions. On the other hand, the results of low carbon dioxide emissions countries are totally opposite from the high carbon emissions countries. The U-Shape relationship between globalization and the carbon emissions in the low carbon dioxide emissions countries might be due to a variety of reasons. Firstly, low carbon emissions countries may have a strict environmental protection policy at the early stage of globalization, when the economy emerges and expand to a certain level, the policy may be loosened to attract and encourage more investment for economic growth. The second reason is probably due to globalization for those low carbon emission countries at the early stage might only focus on the clean technologies exchange, hence the increasing globalization would reduce the carbon dioxide emissions. After reaching a particular point, the integration between countries may be more diverse and this would lead to carbon dioxide increment.

5.2 Implication

There are a few implications in this study. First of all, the inverted U-shape relationship between ICT and carbon dioxide emissions revealed that the G-20 countries' environmental quality is highly associated with ICT in lower carbon dioxide emissions countries. For example, ICT would have a more serious impact in Malta, Cyprus, Latvia, Luxembourg, Estonia, Lithuania, Slovenia, Denmark, Slovak Republic, Sweden, Finland, and Bulgaria among all the G-20 countries. Policies could be implemented to reduce unnecessary ICT use, such as encouraging the use of video conferencing instead of traveling for meetings or promoting the use of electronic documents instead of printing and encouraging, setting energy efficiency standards for ICT equipment, and raising awareness among users about the carbon footprint of their ICT use.

Secondly, this study successfully validated the inverted U-shape relationship between green innovation and carbon dioxide. Policymakers in the 40th to 70th quantiles carbon dioxide emissions countries are suggested to offer incentives such as tax breaks or grants to companies that develop and patent environmentally sustainable technologies. Additionally, policymakers could introduce regulations and standards that encourage developing and adopting such technologies while discouraging the use of environmentally harmful ones. For example, regulations could be put in place to require the use of low-carbon technologies in certain industries or to limit the use of harmful chemicals in manufacturing processes.

Fourthly, the findings confirmed that in countries with lower carbon emissions, there was a U-shaped relationship between globalization and carbon dioxide emissions, while in the high carbon emissions countries, an inverted U-shaped relationship between globalization and carbon dioxide emissions was observed. In this case, the policymakers in G-20 countries could increase international cooperation and agreements on environmental protection measures, the transfer of technology and knowledge related to sustainable energy and practices, the adoption of more efficient and cleaner production methods by businesses in response to global market pressures, and access to international markets and resources, which can help countries shift to more sustainable and lower-emission economic activities to form a sustainable environment. Nevertheless, the impact of globalization on emissions can vary depending on the specific political, economic, and social conditions of a country. Therefore, policymakers should carefully consider the potential benefits and drawbacks of globalization, and design policies that maximize the benefits while minimizing the negative impacts on the environment and society.

5.3 Limitations

This study has some limitations. Firstly, the scope of ICT could be considered from multiple dimensions. For instance, the ICT index which comprises four components, namely internet users, fixed broadband subscriptions, fixed telephone subscriptions, and mobile subscriptions, the number of individuals using the internet, and the ICT goods exports, However, this study only focused on ICT goods imports and cannot reflect the impact of other elements of ICT on carbon dioxide emissions.

Secondly, the independent variable used in this study was the patent application, which included all types of patents, rather than specifically focusing on green innovation. Therefore, this research can only demonstrate the impact of overall patent applications and cannot distinguish the effect of green patent applications, which may indeed an important area Oof concern.

Thirdly, a similar situation exists with another independent variable, the KOF Globalization Index. Apart from the overall globalization index used in this study, the KOF Swiss

Economic Institute has also provided three other indices of globalization, namely economic, social, and political indices. However, this research only utilized the overall globalization index as the indicator of globalization, which limits the ability to provide specific results based on certain aspects of globalization.

5.4 Recommendation for Future Study

For future research investigating the relationship between ICT and environmental quality, it is suggested that scholars incorporate additional factors such as the ICT index, the number of internet users, and the ICT goods exports in the same research area. This approach would enable a more detailed and holistic understanding of how ICT impacts the environment from specific dimensions.

In future studies, it is advisable to focus on green innovation-specific patent applications rather than utilizing overall patent applications. Additionally, considering sub-components of globalization instead of relying on the overall globalization index could provide policymakers with clearer insights for developing related policies.

Overall, incorporating these additional indicators would enhance the accuracy and relevance of research findings and support the development of more effective policies to address environmental challenges.

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