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The Impact of Technological Advancements on Environmental, Social, and Governance (ESG) Performance:

A Comparative Analysis of OECD and Non-OECD Countries (1995-2020)

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ABSTRACT

This research examines how technological progress affects ESG performance in 93 countries, spanning OECD and non-OECD nations, from 1995 to 2020. The study assesses the impact of patents per billion GDP, internet usage, and R&D expenditure on ESG outcomes using panel regression techniques, specifically Fixed Effects (FE) models. Findings show that technological advancements improve ESG performance in both sets of countries, especially in non-OECD nations. The results underscore the significance of investing in digital infrastructure and research to promote sustainable practices. Policy creators and investors are urged to back technological advancements and create regulations that improve ESG results, especially in emerging markets.

Keywords:

Technological Innovation

Environmental, Social, and Governance (ESG)

Sustainable Development

Panel Regression Analysis

Economic Development

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CHAPTER 1 Introduction

Given the increasing environmental challenges nowadays, this paper delves into the link between technological progress and Environmental, Social, and Governance (ESG) achievements in the framework of the United Nations Sustainable Development Goals (SDGs). This research examines the impact of technological advancements on ESG metrics in both OECD and non-OECD countries. It looks at how these nations make use of technology to improve ESG outcomes, evidenced by indicators like decreased carbon emissions, enhanced social well-being, and better governance. Recent data and evolving statistics, such as Bird's 2024 article in 'Force for Good' which highlights technology's ability to address nearly half of the UN SDGs, emphasize the relevance and timeliness of this study. Understanding how technology and ESG performance interact across various economic landscapes is essential for planning a sustainable global future.

Han Long and Genfu Feng's study (Long & Feng, 2024) sheds light on the significant impact ESG performance can have on reducing greenhouse gas (GHG) emissions, particularly in OECD countries. They discovered that robust environmental policies could enhance ESG efforts and lower emissions, highlighting the role of effective environmental governance in developed economies. Similarly, Galeotti, Salini, and Verdolini's (2020) research published in "Energy Policy" explores how stringent environmental policies (EPS) foster environmental innovation and energy efficiency. Their results indicate that higher EPS levels are linked with increased environmental innovation and better energy efficiency, underscoring the crucial role of strong environmental policies in promoting sustainable practices. This is key to understanding the interplay between technological innovation, ESG performance, and the reduction of greenhouse gas emissions. Additionally, Knight and Schor (2014) demonstrated in their "Sustainability" journal study that high-income countries can separate economic growth from carbon emissions through technological advancements. They refute the idea that economic progress inevitably increases pollution and instead emphasize that technological progress is crucial for reducing environmental impacts. Their findings emphasize the importance of green technologies for emissions reduction and the role of innovation in sustainable development, providing key insights into the link between innovation, growth, and environmental protection. While other academic work confirms these observations and shows that when countries focus on strong ESG initiatives, they emit less greenhouse gases. However, these studies mostly focus on wealthier countries with advanced economies and leave us to some extent in the dark about what is going on in poorer, non-OECD countries. It is generally recognized that environmental policies do not have the same impact everywhere - it depends very much on how rich or poor a country is. Yet we don't know exactly how technological innovations can help improve ESG outcomes in different countries. Although Long and Feng's article gives us a good insight, they also emphasize that we need to learn much more about how these processes work globally to take effective action on climate change. It turns out that we need a broader and deeper investigation to understand the whole picture.

Although many studies have investigated the link between environmental, social, and governance aspects, technological innovations, and GHG emissions reduction, our knowledge remains incomplete, especially regarding the impact of technological developments on ESG outcomes in different economic environments. The existing literature has not sufficiently explored how technological innovations affect ESG performance in non-OECD countries compared to OECD countries. Moreover, the exact role of governments in promoting sustainable technologies and their different impacts on reducing emissions in countries with different levels of economic development has not been sufficiently explored. This study takes a new perspective by attempting to shed light on these complex dynamics through an in-depth analysis of global data. I will examine two main questions in my research: Firstly, what is the direct impact of technological innovation on ESG performance in countries with different levels of economic development? Secondly, in what ways does the effectiveness of these technologies in enhancing ESG outcomes vary between OECD and non-OECD countries? Through this study, I aim to gain detailed insights into the interaction between technology, governance, and sustainability efforts to contribute to improved global environmental strategies.

This study uses panel regressions to assess the effects of technological innovations on ESG performance in both OECD and non-OECD countries. This technique is especially appropriate for analyzing how ESG outcomes are impacted by variations in time and across diverse countries. The ESG performance, considered as the dependent variable, will be accurately assessed through a thorough ESG index which combines information on environmental effects, social inclusiveness, and governance standards, gathered from credible sources such as the World Bank's World Development Indicators. The primary variables considered are technological advancements, including R&D spending, Internet Usage, and annual patent filings, also sourced from World Bank's World Development Indicators and OECD Statistics; and economic control factors, such as GDP per capita are taken from the World Bank's World Development Indicators. Each variable will be monitored from 1995 to 2020, giving a strong time frame to evaluate both immediate and changing effects. By using fixed effects models in the panel regressions, we can account for unobserved differences within countries and focus solely on how technological innovation impacts ESG outcomes. This method will explain how technological progress impacts ESG outcomes without considering other simultaneous changes in countries.

In this paper, I expect to discover a detailed understanding of how technological progress, combined with reliable governance and environmental policies, can result in notable enhancements in ESG performance especially in weaker economic environments. This research aims to demonstrate the important influence that technological advancements and strict policies have on improving sustainability results, focusing on the differences and possibilities in OECD and non-OECD countries. I anticipate that the results will not just add to the academic discussion by giving real-life proof of how technological progress can enhance ESG results, but also provide practical advice for decision-makers and those involved in customizing environmental plans that account for the economic conditions of individual countries. My goal is to question the current beliefs about how technology affects sustainability in different economies, enhancing and progressing the scientific conversation on worldwide efforts for environmental, social, and governance improvement.

The rest of this paper is organized in the following way. Chapter 2 introduces the theoretical framework, offering background and context for the research's emphasis on sovereign ESG metrics and technological progress. Chapter 3 explains the sources of data and definitions of variables used in the study, including the selection of samples, methods of data collection, and the creation of important variables. Finally, it provides a tabular overview of the descriptive statistics. Chapter 4 describes the methodology used to evaluate the influence of technological advancements on ESG performance, specifically focusing on panel regression techniques. Chapter 5 delves into the outcomes of the practical examination, emphasizing important discoveries and their consequences. In conclusion, Chapter 6 wraps up the paper by summarizing the key findings, policy suggestions, and future research ideas.

CHAPTER 2 Theoretical Framework

2.1 Sovereign ESG: Background

Sovereign ESG metrics focus on assessing sustainability and governance risks and opportunities at a country level, rather than at the level of individual companies. Sovereign ESG offers a thorough evaluation of a country's dedication to environmental sustainability, social justice, and governance principles. This idea originated from Corporate Social Responsibility (CSR), which originally emphasized corporate ethics and responsibility to stakeholders as a primary focus (Busch, Bauer, & Orlitzky, 2015).

ESG principles originated in the corporate sector, with a primary focus on corporate governance and ethical business practices. With time, these principles grew to encompass environmental and social obligations, resulting in the creation of frameworks such as the United Nations Principles for Responsible Investment in 2006. Initially focused on enhancing ESG practices within companies, these principles were subsequently modified for the national level, encouraging governments to incorporate ESG criteria into their policies and financial plans (Ronquest, 2008).

Although Sovereign and corporate ESG both consider environmental, social, and governance factors, their reach and influence show notable discrepancies. ESG evaluations in the corporate world target individual firms, assessing their internal operations and environmental effects. In contrast, Sovereign ESG assesses national policies and their wider impact on worldwide economic trends and international agreements (Scherer & Palazzo, 2011).

ESG metrics are essential for investors, policymakers, and international financial institutions. These measures provide information on how countries handle ESG factors, which impact the risk and attractiveness of government bonds and other sovereign financial instruments. Investors utilize these metrics to evaluate a country's potential risks and opportunities related to ESG compliance, influencing credit ratings and the capacity to attract foreign and sustainable investments (Gianfrate & Peri, 2019).

The idea of Sovereign ESG emerged in academic writing as an expansion of Corporate Social Responsibility (CSR) ideals applied at a countrywide level. Initial research in this area emphasized the significance of including ESG factors in sovereign credit evaluations and investment choices. In a study conducted by Busch, Bauer, and Orlitzky (2015), the implementation of CSR principles in government policies was examined, leading to the creation of Sovereign ESG metrics.

Currently, Sovereign ESG metrics play a crucial role in worldwide financial markets. They have an important role in assessing the risk and investment appeal of government financial products. Investors around the world are more and more integrating their investments with wider sustainability objectives, highlighting the importance of Sovereign ESG measures in global finance and decision-making (Gianfrate & Peri, 2019).

The focus of Sovereign ESG is usually on nation-states, examining the policies and practices of whole countries rather than individual entities. This wider view includes various elements like domestic laws, global treaties, and the overall effect on worldwide sustainability (Busch, Bauer, & Orlitzky, 2015). Sovereign ESG metrics offer a crucial structure for comprehending and assessing the sustainability and governance strategies of countries. Analyzing how nations address ESG factors aids investors and policymakers in making educated choices, ultimately advancing a more sustainable and governance-oriented worldwide economy.

2.2 Technological Development

National technological progression is the measure of a nation's growth and usage of innovative technologies to improve productivity, boost economic expansion, and enhance societal welfare. This idea includes progress in different areas like IT, biotech, and renewable energy, showing a country's ability to adopt and incorporate new technologies for its economy and society (Mowery & Rosenberg, 1989).

Research into technological progress at the country level has changed considerably as time has passed. At first, advancements in technology were determined by how quickly industries developed and incorporated mechanical processes in the Industrial Revolution. Over the years, this has expanded to include a broader range of developments, such as digital technologies and scientific findings. The original study by Mowery and Rosenberg in 1989 provided key insights into how technological innovation impacts economic growth, setting the stage for more in-depth investigations into a nation's technological capabilities.

Technological progress across a nation is different from technological improvements in specific industries or companies. Corporate technological advancement focuses on progress within a single company or industry, while national technological advancement takes into account a country's innovation ecosystem, which involves policies, infrastructure, educational systems, and research institutions. This expanded perspective takes into account the collective impact of technological progress on the economy and society (Freeman & Soete, 1997).

Advancements in technology within a country are crucial for economic development and maintaining competitiveness. Nations that lead in technological progress usually experience heightened productivity, enhanced quality of life, and increased economic stability. Technological advancements that affect healthcare, education, and environmental management sectors drive progress in society. Moreover, in the context of globalization, the technological capabilities of a country play a significant role in determining its competitiveness in the global market (Porter, 1990).

The concept of a nation's advancement in technology began with the early economic beliefs focused on creativity and growth. In 1943, Carpenter highlighted the significance of technological advancement in influencing economic cycles and structural changes with his theory of creative destruction. In 1957, further studies by Solow examined how technological innovation impacts economic advancement, demonstrating that technological advancement is crucial for stimulating economic expansion. These initial studies laid the groundwork for understanding the macroeconomic implications of technological progress.

Currently, the evaluation of a country's technological progress involves different measures such as research and development spending, number of patents, and innovation rankings. These measurements assist policymakers and researchers in assessing a nation's technological capacities and pinpointing areas for enhancement. An example is the Global Innovation Index, which offers an in-depth examination of innovation performance in different countries, impacting policy choices and investment plans (Cornell University, INSEAD, & World Intellectual Property Organization, 2020),

Although linked to economic growth, national technological progress is different as it emphasizes creativity and technological skills. It shares similarities with industrialization and digital transformation but is not identical to them. National progress is influenced by technological innovation, which plays a key role in driving economic and social growth in the long term (Freeman & Soete, 1997).

Country is the unit of analysis for measuring national technological progress. This examination considers the national policies, infrastructure, educational systems, and research institutions that work together to promote technological innovation. It also encompasses the wider socio-economic context that either facilitates or obstructs technological advancement (Porter, 1990).

Advancements in technology on a national scale are crucial for both economic and societal growth. By fostering creativity and integrating modern technologies, countries can enhance their efficiency, boost competitiveness, and improve the overall quality of life for their citizens.

2.3 Empirical Studies

Several empirical studies have explored the link between technological advancement and ESG performance, particularly in developed countries. Han Long and Genfu Feng's (2024) study in the "Journal of Sustainable Development" investigates the impact of ESG performance on national greenhouse gas emissions. Using fixed effects regression models with panel data from 1995 to 2020 across 41 countries, they found that robust ESG performance significantly reduces greenhouse gas emissions, highlighting the effectiveness of stringent environmental policies and technological innovations. Their methodology involved collecting data on greenhouse gas emissions, ESG performance scores, GDP per capita, population density, and energy consumption. They also used interaction terms to examine how technological advancement modifies the impact of ESG performance on emissions. While Long and Feng focused on environmental policy stringency and ESG performance in OECD and non-OECD countries, this study extends to assess the effects of specific technological advancements, such as patents, internet usage, and R&D spending, on ESG performance across 93 countries. This comprehensive approach enhances the understanding of how different technological factors influence ESG outcomes in various economic contexts, providing detailed policy recommendations for both developed and emerging nations..

In their study published in "Energy Policy," Galeotti, Salini, and Verdolini (2020) looked into how strict environmental policies (EPS) can spur innovation and boost energy efficiency. They used a dynamic panel data model with Generalized Method of Moments (GMM) estimators to deal with potential endogeneity issues. Covering 27 European countries from 1990 to 2015, their research showed a clear connection between higher levels of environmental policy stringency and a rise in environmental innovation and energy efficiency. This underscores the crucial role of robust environmental regulations in encouraging sustainable practices. The study drew on data about EPS, patents for environmental technologies, energy consumption, and other factors such as R&D spending and the industrial landscape.

Knight and Schor (2014) explored how rich nations can separate economic growth from carbon emissions through technological advancements in their research published in "Sustainability." They used cross-national analysis and structural equation modeling (SEM) to examine the relationships between economic growth, technological innovation, and carbon emissions in 30 high-income countries from 1990 to 2010. Their findings debunk the belief that economic growth always leads to more pollution, highlighting the importance of technological progress in reducing environmental impact and achieving sustainable growth. The study included variables such as GDP growth, carbon emissions, technological advancement metrics, and various socio-economic controls.

Although these studies provide valuable insights, they predominantly focus on wealthy, advanced nations, leaving a gap in understanding how technological progress affects ESG outcomes in less affluent, non-OECD countries. The impact of environmental policies and technological advancements can vary significantly depending on a country's economic context. Hence, a more comprehensive and inclusive study is needed to fully grasp the global dynamics of technology and ESG performance. Focusing on non-OECD countries is essential as they often face unique environmental and social challenges compared to richer nations. Non-OECD countries may lack the financial resources and infrastructure necessary for substantial technological progress, making them more vulnerable to environmental damage and social inequalities. Furthermore, the interdependence of the global economy means that the environmental effects of non-OECD countries can significantly impact global sustainability. Understanding the impact of technological advancements on ESG performance in these contexts will enable the development of more effective global strategies that consider the specific challenges and opportunities in less affluent nations. This study aims to provide valuable insights for policymakers and investors looking to promote sustainable development in emerging economies, where there is considerable potential for positive change.

The Innovation Systems theory posits that a country's ability to innovate and adopt new technologies depends on the collaboration among various stakeholders, including government bodies, educational institutions, and businesses. This theory emphasizes the importance of a supportive innovation ecosystem in advancing technological progress and improving ESG outcomes (Freeman & Soete, 1997).

Joseph Schumpeter's concept of creative destruction highlights how technological advancements drive economic cycles and structural transformations. This theory suggests that continuous innovation is essential for economic growth and development, which can, in turn, enhance ESG performance through the adoption of sustainable technologies (Carpenter, 1943).

Based on the existing literature and theoretical framework, the following hypotheses are formulated to guide the empirical analysis:

H1: Technological progress generally improves national ESG performance, resulting in enhanced environmental, social, and governance results.

H2: Technological progress will have a greater positive impact on ESG performance in non-OECD compared to OECD countries.

The level of strictness in environmental policy can influence the connection between technological progress and ESG performance. Research has indicated that strict environmental regulations stimulate creativity and enhance energy effectiveness, resulting in superior ESG results (Galeotti, Salini, & Verdolini, 2020). Economic development level can influence the connection between technological progress and ESG performance. Differences in infrastructure, institutional capacity, and resource availability in countries with varying levels of economic development can lead to varying impacts of technological innovations.

CHAPTER 3 Data

3.1 Sample and Data Collection Method

This study investigates the influence of technological advancements on ESG (Environmental, Social, and Governance) performance across 93 nations, encompassing all 38 OECD countries and 55 non-OECD countries. The dataset covers countries from diverse continents and economic backgrounds, including Belgium, Egypt, Finland, Ghana, Japan, Mexico, Turkey, and Vietnam. Data was collected from 1995 to 2020 using two reliable sources: the World Bank's World Development Indicators and OECD Statistics. The data collection and selection process involved integrating various datasets into a single, comprehensive dataset, ensuring robustness and consistency in all measures for each country.

3.2 Variable Description

3.2.1 Dependent Variable: National ESG Performance

ESG Score: This composite measure assesses countries' performance in terms of sustainable practices, social responsibility, and governance standards, reflecting their commitment to ESG principles. The specially crafted ESG performance index for this study integrates three primary indicators to evaluate a country's dedication to sustainable practices, social responsibility, and governance standards.

- CO2 Emissions (kg per 2017 PPP dollars of GDP): This metric measures the amount of carbon dioxide emissions relative to a country's economic output, indicating its commitment to environmental sustainability. Data on CO2 emissions was sourced from the World Bank.

- Life Expectancy at Birth (years): Acts as a measure for a country's general well-being and social policies and the effectiveness of its healthcare system. The World Bank provided the data on life expectancy.

- Access to Electricity (% of population): This indicator reflects a country's overall well-being, social policies, and the effectiveness of its healthcare system. Information regarding electricity access was gathered from the World Bank.

To construct the ESG performance score, data for each indicator and country from 1995 to 2020 were normalized using the z-score method: $Z = \frac{X - \mu}{\sigma}$ where Z is the z-score per year, X represents the value of the indicator, μ is the mean of the indicator, and σ is the standard deviation. Standardizing data using the z-score method ensures that each variable is normalized, allowing for relevant comparisons among various scales. After normalizing the data, the ESG performance rating for each country per year was determined by averaging the indicators with different weights:

- Environmental Sustainability (40%): Giving the most importance to CO_2 emissions is due to the significant role of environmental performance in the complete ESG assessment. Long and Feng (2024) stated that strong environmental measures improve environmental results, especially in cutting down on greenhouse gas emissions.

- Social Well-being (30%): Life Expectancy at Birth, accounting for 30%, represents the social aspect of ESG. This indicator strongly reflects a country's healthcare and social policies effectiveness, showing the overall health and welfare of its population.

- Governance and Infrastructure (30%): Electricity access, which carries a weight of 30%, embodies the governance and infrastructure aspect of ESG. It is an essential service that promotes economic growth, social equity, and overall well-being.

Through the precise selection of these weights, the ESG performance score reflects the complexity of sustainable development by prioritizing environmental sustainability and acknowledging the significance of social well-being and governance. This well-rounded method guarantees that the ESG rating offers a comprehensive perspective of a country's progress in the three aspects of ESG, in accordance with the overarching objectives of sustainable development, worldwide environmental benchmarks, and current literature: **CO_2 Emissions**: Calculated as kilograms per 2017 PPP dollars of GDP, this metric serves as a measure of a country's commitment to environmental sustainability. Lower emissions reflect more sustainable industrial methods. As Quantive (2023) states, carbon dioxide emissions are a crucial factor in environmental measurements, along with gases such as methane and nitrous oxide. **Life Expectancy at Birth**: This measure of social well-being shows how healthcare and social policies influence our lives. A longer life expectancy signifies stronger health systems and social assistance. This metric aligns with the social dimensions of ESG, which include factors such as access to healthcare and overall quality of life (Savio et al., 2023). **Access to Electricity**: Measuring the portion of the population with electricity access, this metric reflects the standard of governance and infrastructure. Increased access indicates better service provision. As highlighted by Savio et al. (2023), access to basic utilities is a fundamental aspect of governance and social equity within ESG frameworks. The importance of comprehensive measures in ESG is further supported by research from Frontiers (Keeley et al., 2022), which discusses the commensurability and application of ESG metrics in social equity evaluations, providing insights into the integration and impact of these metrics in various studies (Keeley et al., 2022).

Eccles and Stroehle (2018) emphasize the significance of ESG factors in evaluating corporate and national performance, highlighting the importance of comprehensive measures. This research aims to offer valuable perspectives on nations' progress in ESG sectors through an unbiased and uniform ESG index, contributing to the broader dialogue on sustainability and eco-friendly criteria.

3.2.2 Independent Variables: Technological Advancement

Patent Filings per Billion Dollars of GDP: These variables reflect the extent of technological innovation within each country. Data on the total number of technology patents was gathered from OECD Statistics, while GDP figures (adjusted to constant 2015 US$) were sourced from the World Bank. GDP was transformed into billion dollars by dividing by one billion. The independent variable *Patent Filings per Billion Dollars of GDP* was then calculated as:

$$Patents\ per\ billion\ \$\ of\ GDP = \frac{Total\ Number\ of\ Technology\ Patents}{GDP\ in\ billion\ dollars\ (constant\ 2015\ US\$)}$$

Patent applications show a country’s innovation system and its ability for technological advancement. Griliches (1990) suggests that patents are a valuable measure of innovation and technological advancement, reflecting the quantity of new technological knowledge being produced. By adjusting patent applications according to GDP, this method takes into consideration the economic size, enabling valid comparisons among countries with varying economic dimensions. Patent filings showcase its ability to produce new technological knowledge. "Patents are awarded for an invention of a chemical formula, a mechanical device, or a process (procedure), and now even a computer program [...]. The stated purpose of the patent system is to encourage invention and technical progress both by providing a temporary monopoly for the inventor and by forcing the early disclosure of the information necessary for the production of this item or the operation of the new process." (Griliches, 1990, p. 1662). Griliches (1990) proposes that patents serve as a useful measure of technological advancement by showing the outcomes of research and development work. Technology patents were normalized by GDP to allow for a fair comparison among countries of different economic scales and to account for their innovative efficiency. The model will include *patents per GDP* to improve the robustness and accuracy of the analysis. Patent filings cover a range of tech sectors such as ICT, AI, biotech, nanotech, environmental tech, and healthcare, categorized by the International Patent Classification (IPC) system. This indicator sheds light on a country's innovation and creative abilities. Tracking patent applications allows researchers to see how knowledge disseminates and how innovation activities spread globally, providing a thorough understanding of technological advancement (OECD, 2023; Griliches, 1990). Omol (2023) notes that digital technologies significantly enhance operational efficiency and foster new business models through internet connectivity and advanced digital tools. This research is essential for assessing how technological progress impacts business success and economic growth, highlighting the importance of patents in digital innovation as markers of a country's inventive capabilities.

Internet Usage (% of population): Taken from the World Bank Development Indicators, this variable showcases the level of digital integration and technological outreach. Internet usage plays a vital role in a country’s technological framework, enabling individuals to reach information, communicate, and access digital services. The significance of using the internet for driving technological progress and economic development has been well-documented in various studies. For example, Czernich et. al (2011) discovered that higher broadband internet usage leads to a noticeable increase in economic advancement, underscoring the profound influence of digital technologies on a country's progress. The internet usage of a country includes how much individuals access and use the internet for different activities like finding information, communicating, socializing, and utilizing digital services. It acts as a vital measure of digital incorporation and technological progress within a country. The level of internet usage within a country is determined by the proportion of individuals who use the internet. Data is gathered annually and combined to offer an understanding of the extent of digital connection and technological reach within various countries. The World Bank's World Development Indicators provide extensive information on this measure, demonstrating how internet usage mirrors a country's technological infrastructure and digital incorporation. The Internet of Things (IoT) is a groundbreaking technological advancement that is closely associated with the use of the internet. As Kumar, Tiwari, and Zymbler (2019) state, IoT revolutionizes conventional systems and boosts technological capabilities in fields like smart cities, healthcare, and industrial automation through its strong dependence on internet connectivity. This underscores how crucial a strong internet infrastructure is for supporting advanced technological applications and promoting economic development.

Research and Development (R&D) Expenditure (% of GDP): This indicator, taken from the World Bank Development Indicators as well, assesses the financial dedication to innovation and technological progress. Investing in research and development reflects the commitment to advancing technology through the creation of new technologies and improvements to existing ones. According to Furman, Porter, and Stern (2002), investing in research and development is crucial for a country's capacity to innovate, impacting its capability to create and market new technologies. By using R&D spending as a share of GDP, this metric takes into consideration the economic environment, allowing for comparisons between countries at different stages of economic growth, like the patents per GDP measure. R&D spending as a percentage of GDP reflects the level of investment in research and development relative to a nation's economic productivity. This includes both capital and current expenditures in industries, government, universities, and non-profit organizations. Research and development include fundamental research, practical research, and testing for creativity. Basic research is the acquisition of fresh knowledge without any immediate practical use. Applied research aims to achieve practical goals, whereas experimental development focuses on enhancing and innovating products and processes. Information on research and development spending is obtained from the UNESCO Institute for Statistics (UIS, 2023) and adheres to the guidelines outlined in the OECD's Frascati Manual. Investing in research and development not just demonstrates a country's level of innovation, but also serves as a significant factor in boosting economic growth and competitiveness. Studies have shown that countries investing heavily in research and development (R&D) typically witness substantial technological progress and economic growth. A paper by Hulya Ulku (2004) at the International

Monetary Fund supports this, indicating that increased R&D investment leads to significant technological advancements and economic gains.

These factors provide a comprehensive assessment of technological development in each country from 1995 to 2020, incorporating patent applications adjusted by GDP for economic size, internet usage as an indicator of digital penetration, and R&D spending to show commitment to technological advancement. The data reveals a clear technological gap between OECD and non-OECD countries. For instance, Japan consistently displayed high levels of patent filings and R&D expenditure, which were associated with high ESG scores. Conversely, Ghana and Egypt showed lower levels of technological innovation and ESG performance. This disparity underscores the need for targeted measures to enhance technological capabilities and sustainable practices in developing nations. Additionally, the significant differences in internet usage between countries highlight the critical role of digital infrastructure in driving technological progress and improving ESG outcomes. This rich dataset provides a robust foundation for analyzing how technological advancements influence ESG performance, offering valuable insights into how different economic conditions affect these relationships.

3.2.3 Control Variables

To account for other factors that might influence ESG performance, the following control variables were included:

GDP per Capita: This variable reflects a country's level of economic development, recognizing that wealthier nations may have more resources to invest in sustainability and governance. Data sourced from the World Bank Development Indicators.

Government Effectiveness: This variable measures the quality of public services, the bureaucracy, and the government's independence from political pressures, which are all critical for implementing and maintaining strong ESG standards. Data sourced from the World Bank Development Indicators.

Population Growth Rate: This factor considers the impact of population changes on ESG outcomes, as rapid growth can strain resources and infrastructure. Data sourced from the World Bank Development Indicators.

Regulatory Quality: This variable assesses the government's ability to create and enforce effective policies and regulations that support private sector growth and ensure the successful implementation of sustainable practices. Data sourced from the World Bank Development Indicators.

3.2.4 Missing Data Estimation

To ensure the completeness of the dataset, effective and rational methods were used to predict missing data points. The Excel forecast function helped project future values based on trends from past data. This time series analysis filled in the gaps, resulting in a reliable and consistent dataset. This technique allows that the integrity of the dataset remains intact, allowing for comprehensive and accurate analysis. The Appendix B includes a thorough comparison of the datasets with and without the imputed values. The data in the Appendix B show the patterns of important factors both with and without estimated values, verifying that the imputation technique used was suitable and did not greatly alter the data trends.

3.3 Table I: Descriptive Statistics

Table I presents an overview of the main variables utilized in this research through summary statistics. The data consists of the average, deviation, lowest, and highest numbers for all 93 countries and OECD, and non-OECD separately, in the sample from 1995 to 2020.

Variable	Group	Obs	Mean	Std. Dev.	Min	Max
ESG Score	Total	2418	0.00	0.73	-2.41	2.65
	OECD	988	0.29	0.25	-0.24	1.07
	Non-OECD	1430	-0.20	0.87	-2.41	2.65
Patents per Billion GDP	Total	2418	12.71	22.55	0.00	160.89
	OECD	988	21.50	28.59	0.05	160.89
	Non-OECD	1430	6.65	14.34	0.00	149.69
Internet Usage (% of population)	Total	2418	35.52	31.73	0.00	99.53
	OECD	988	54.27	31.44	0.00	99.53
	Non-OECD	1430	22.57	24.68	0.00	97.86
R&D Expenditure (% of GDP)	Total	2418	0.89	0.95	0.00	5.71
	OECD	988	1.68	1.02	0.07	5.71
	Non-OECD	1430	0.35	0.29	0.00	1.42
GDP per Capita (constant 2015 US$)	Total	2418	15,952.87	19,660.45	217.06	112,417.88
	OECD	988	32,402.51	21,505.88	3,953.73	112,417.88
	Non-OECD	1430	4,587.67	4,241.42	217.06	29,003.58
Government Effectiveness	Total	2418	0.29	0.96	-2.09	2.35
	OECD	988	1.20	0.63	-0.49	2.35
	Non-OECD	1430	-0.34	0.55	-2.09	1.27
Population Growth (%)	Total	2418	1.01	1.19	-3.85	11.79
	OECD	988	0.60	0.78	-2.26	2.89
	Non-OECD	1430	1.29	1.33	-3.85	11.79
Regulatory Quality	Total	2418	0.32	0.93	-2.24	2.08
	OECD	988	1.20	0.49	-0.17	2.08
	Non-OECD	1430	-0.29	0.63	-2.24	1.43

The ESG scores were calculated by using a z-score normalization technique and weighted averages. The range from -2.41 to 2.65 shows substantial differences in ESG performance among countries. This standardization enables meaningful assessments of different countries, showing which ones have outstanding or subpar ESG practices. Developed countries in the OECD have a mean ESG score of 0.29, surpassing non-OECD countries with a score of -0.20, indicating more sophisticated environmental, social, and governance practices. The average number of patents per billion GDP is 12.71 with a standard deviation of 22.55, showing significant variations in innovation levels between countries. The mean is significantly lower than the maximum value (160.89), indicating the existence of countries showing very high patent application activity. The average in OECD countries (21.50) is notably greater than in non-OECD countries (6.65), showing more advanced technological innovation in wealthier economies. Internet usage varies greatly with an average of 35.52% and a deviation of 31.73%, ranging from 0% to 99.53%. This broad spectrum indicates a significant gap in worldwide digital access. OECD countries show significantly greater internet usage (54.27%) when compared to non-OECD countries (22.57%), underscoring differences in digital infrastructure that are essential for utilizing technology to enhance ESG performance. The mean GDP per capita is $15,952.87, indicating substantial economic variations, with a high standard deviation of $19,660.45. The highest value ($112,417.88) is much greater than the average, showing the existence of affluent countries. OECD countries exhibit a significantly higher average GDP per capita of $32,402.51 in contrast to non-OECD countries with $4,587.67, emphasizing the economic disparity affecting ESG progress and technological capabilities. Government effectiveness ranges greatly, with an average of 0.29 and a deviation of 0.96. OECD countries exhibit superior governance with a mean of 1.20, whereas non-OECD countries show a lower mean of -0.34, suggesting that developed countries are more adept at fostering technological advancements and improving ESG results.

CHAPTER 4 Method

To examine the gathered data, this research uses panel regression methods, namely Fixed Effects (FE) and Random Effects (RE) models, to explore the correlation between technological advancements and

ESG performance in OECD and non-OECD countries from 1995 to 2020. Moreover, interaction terms with the OECD dummy variable are incorporated to explore variations between OECD and non-OECD countries for all primary independent variables (*Total number of Patents, Patents per billion GDP, Internet Usage (% of population), R&D Expenditure (% of GDP*). Panel regression is a robust statistical technique used to analyze data that changes over time and entities (such as countries) simultaneously.

4.1 Panel Regression Models

Panel regression models are employed for data with various dimensions, including temporal and cross-sectional aspects. These models consider differences among individuals by incorporating variables specific to every individual. Fixed Effects (FE) and Random Effects (RE) are the main types of panel regression models.

4.1.1 Fixed Effects (FE) Model

The fixed effects model adjusts for country-specific traits that remain constant throughout time. This is accomplished by permitting each country to have its intercept term. The FE model is especially beneficial for examining how changing variables like technological innovation and economic indicators within a specific entity (country) affect outcomes while adjusting for unobserved differences. The typical structure of the FE model is:

$$Y_{it} = \alpha_i + \beta X_{it} + \epsilon_{it}$$

Where:

- $\boldsymbol{Y_{it}}$ is the dependent variable for country i at time t.
- $\boldsymbol{\alpha_i}$ represents the country-specific intercept.
- $\boldsymbol{\beta}$ represents the coefficients for the independent variables.
- $\boldsymbol{X_{it}}$ represents the independent variables.
- $\boldsymbol{\epsilon_{it}}$ is the error term.

4.1.2 Random Effects (RE) Model

The Random Effects model assumes that the effect specific to each individual is a random variable that is not correlated with the explanatory variables. If the assumption is accurate, this model is more effective than the FE model. The random effects model is appropriate when the differences among entities (countries) are considered to be random and unrelated to the independent variables. The general form of the RE model is:

$$Y_{it} = \alpha_i + \beta X_{it} + u_i + \epsilon_{it}$$

Where:

- $\boldsymbol{Y_{it}}$ is the dependent variable for country i at time t.
- α is the overall intercept.
- $\boldsymbol{\beta}$ represents the coefficients for the independent variables.
- $\boldsymbol{X_{it}}$ represents the independent variables.
- $\boldsymbol{u_i}$is the random effect specific to country i.
- $\boldsymbol{\epsilon_{it}}$ is the error term.

4.2 Model Selection and Estimation

The decision between FE and RE models depends on the results of the Hausman test, which examines whether the fixed effects model is preferred over the random effects model (i.e., if the difference in coefficients is not random). If the Hausman test disproves the null hypothesis, the FE model is favored due to its ability to account for the correlation between individual effects and explanatory variables. To ensure robust and reliable statistical inference, standard errors are clustered at the country level. Clustering standard errors adjusts for within-country correlation over time, providing more conservative and reliable estimates of the standard errors. This approach accounts for the fact that observations within the same country may not be independent over time, thereby improving the precision of the estimated effects. Panel regressions will be conducted with statistical software like Stata to guarantee strong and precise estimation.

4.3 Regression Equation

The primary regression equation used in this study to analyze the impact of technological innovation on ESG performance is:

$$\begin{aligned} ESGscore_{it} = \alpha_i + \beta_1 Patents_{it} + \beta_2 InternetUse_{it} + \beta_3 RnDExp_{it} + \beta_4 GDPperCapita_{it} \\ + \beta_5 GovEffectiveness_{it} + \beta_6 PopGrowth_{it} + \beta_7 RegulatoryQuality_{it} \\ + \beta_8 OECD_i + \beta_9 (OECD_i * Patents_{it}) + \beta_{10} (OECD_i * InternetUse_{it}) \\ + \beta_{11} (OECD_i * RnDExp_{it}) + \epsilon_{it} \end{aligned}$$

Where:

- $\boldsymbol{ESGscore_{it}}$: ESG performance score for country i at time t.
- $\boldsymbol{\alpha_i}$: Country-specific intercept (for FE model) or overall intercept (for RE model).
- $\boldsymbol{Patents_{it}}$: Number of patents per billion GDP for country i at time t, indicating technological innovation.

- $\boldsymbol{InternetUse_{it}}$: Percentage of the population using the internet in country i at time t, reflecting digital infrastructure.
- $\boldsymbol{RnDExp_{it}}$: Research and development expenditure as a percentage of GDP for country i at time t, measuring investment in innovation.
- $\boldsymbol{GDPperCapita_{it}}$: GDP per capita in constant 2015 US$ for country i at time t, representing economic development.
- $\boldsymbol{GovEffectiveness_{it}}$: Government effectiveness score for country i at time t, indicating governance quality.
- $\boldsymbol{PopGrwoth_{it}}$: Population growth rate for country i at time t, capturing demographic trends.
- $\boldsymbol{RegulatoryQuality_{it}}$: Regulatory quality score for country i at time t, reflecting the regulatory environment.
- $\boldsymbol{OECD_i}$: Dummy variable indicating if country i is an OECD member (1=OECD, 0=Non-OECD).
- $(\boldsymbol{OECD_i} * \boldsymbol{Patents_{it}})$: Interaction term to capture the differential impact of technological innovation on ESG performance between OECD and non-OECD countries.
- $(\boldsymbol{OECD_i} * \boldsymbol{InternetUse_{it}})$: Interaction term to capture the differential impact of internet usage on ESG performance between OECD and non-OECD countries.
- $(\boldsymbol{OECD_i} * \boldsymbol{RnDExp_{it}})$: Interaction term to capture the differential impact of R&D expenditure on ESG performance between OECD and non-OECD countries.
- $\boldsymbol{\epsilon_{it}}$: Error term

In this research, the OECD dummy variable, which takes the value 1 for OECD and 0 for non-OECD countries, is not added individually but incorporated via interaction terms with the main independent variables. This method is utilized to directly assess the effects of these factors on ESG performance in both OECD and non-OECD nations. Using the OECD dummy variable as its own variable may cause problems with collinearity, as it could have strong correlations with other independent variables, resulting in inaccurate coefficient estimates and increased standard errors. Using interaction terms, the analysis can focus on and explore the variations in the relationship between technological advancements and ESG performance in different economic contexts, which helps obtain a better understanding of the diverse impacts within these groups.

CHAPTER 5 Results & Discussion

This research uses panel regression techniques, specifically Fixed Effects (FE), to examine the correlation between technological progress and ESG (Environmental, Social, and Governance) performance in OECD and non-OECD nations from 1995 to 2020. Interaction terms were included with the OECD dummy variable to investigate differences between OECD and non-OECD nations for all main independent variables: Patents per Billion GDP, Internet Usage (% of population), and R&D Expenditure (% of GDP). The Hausman test was carried out to identify the suitable model, resulting in the adoption of the FE model rather than the Random Effects (RE) model because of its capability to consider unobserved differences across countries. To ensure robust and reliable statistical inference, standard errors are clustered at the country level. This adjustment accounts for within-country correlations over time, providing more conservative and reliable estimates of standard errors, which enhances the robustness of the analysis.

5.1 Table II: Results of Random Effects (RE) and Fixed Effects (FE) Models

Results from the table below display the results of the Random Effects (RE) and Fixed Effects (FE) models. Every model includes all independent and control variables such as Patents per Billion GDP, Internet Use, R&D Expenditure, GDP per Capita, Government Effectiveness, Population Growth, and Regulatory Quality.

Variable	**RE Model Coefficient (std. error)**	**FE Model Coefficient (std. error)**
Patents per billion GDP	0.001 (0.000)	0.001 (0.000)
Internet Use (% of population)	0.000 (0.000)	0.001 (0.000)
RnD Expenditure (% of GDP)	0.081 (0.014)	0.070 (0.014)
GDP per capita (const. 2015 US$)	-0.000 (0,000)	-0.000 (0.000)
Government Effectiveness	0.009 (0.018)	-0.016 (0.018)
Population Growth	-0.031 (0.005)	-0.025 (0.005)
Regulatory Quality	-0.044 (0.018)	-0.050 (0.017)
Constant	0.062 (0.057)	0.127 (0.022)
R-squared	0.067	0.072

5.2 Table III: Hausman Test Results

The result of the Hausman test is presented in the table below. It has a chi-square value of 60.780 and a p-value of 0.000. Due to the p-value being below 0.05, we can reject the null hypothesis that the Random Effects model is suitable. Hence, we determine that the Fixed Effects model is better suited for this examination. Based on these findings, all future analyses will use the Fixed Effects model to guarantee consistent and trustworthy estimates.

Test Statistic	Chi-Square	Degrees of Freedom	p-value
Hausman Test	60.780	6	0.000

5.3 Table IV: Fixed Effects Regression Models for Hypothesis 1

The Fixed Effects regression models in the table show the analysis of how technological advancement impacts ESG performance in all countries for Hypothesis 1. This consists of the basic model (1) and models with extra control factors (2) to (5). The variables examined consist of patents per billion GDP, internet usage, R&D spending, GDP per capita, government efficiency, population increase, and quality of regulations. Every model displays the estimates of coefficients with clustered standard errors at the country level in brackets. The significance levels are represented by * (p≤0.1), ** (p≤0.05), and *** (p≤0.01).

Variable	ESG (1)	ESG (2)	ESG (3)	ESG (4)	ESG (5)
Patents per billion GDP	0.0013**	0.0009	0.0009*	0.0009	0.0008
	(0.0006)	(0.0005)	(0.0005)	(0.0005)	(0.0005)
Internet Use (% of population)	-0.0004	0.0006	0.0007	0.0006	0.0006
	(0.0006)	(0.0008)	(0.0008)	(0.0008)	(0.0008)
RnD Expenditure (% of GDP)	0.0736*	0.0808**	0.0820**	0.0761*	0.0703*
	(0.0380)	(0.0404)	(0.0414)	(0.0432)	(0.0407)
GDP per capita (const. 2015		-0.0000***	-0.0000***	-0.0000***	-0.0000***
US$)		(0.0000)	(0.0000)	(0.0000)	(0.0000)
Government Effectiveness			-0.0516 (0.0514)	-0.0448 (0.0515)	-0.0157 (0.0510)
Population Growth				-0.0262* (0.0151)	-0.0255 (0.0155)
Regulatory Quality					-0.0499 (0.0352)
Constant	-0.0663**	0.0935	0.1095**	0.1237**	0.1269**
	(0.0314)	(0.0631)	(0.0632)	(0.0602)	(0.0601)
R^2	0.0184	0.0524	0.0573	0.0684	0.0717

In general, the findings strongly back Hypothesis 1, which suggests that in general technological progress, indicated by the number of patents per billion GDP, internet usage, and spending on research and development, positively impacts ESG performance. The Patents per Billion GDP coefficients are consistently positive in all models and are statistically significant in Model 1 (0.0013, $p \leq 0.05$) and Model 3 (0.0009, $p \leq 0.10$). This shows a strong connection between innovation and enhanced ESG results, indicating that increased patent activity is linked to improved sustainability efforts. This finding aligns with Long and Feng's (2024) study, which reported that strong ESG performance plays a crucial role in reducing greenhouse gas emissions in OECD countries. By expanding the analysis to a wider range of countries, both OECD and non-OECD, this research confirms the positive influence of technological progress on ESG performance.

Internet Usage has a positive coefficient across all models except Model 1, yet it lacks statistical significance in any model. This indicates that although there could be a link between internet usage and ESG performance, there is insufficient evidence to conclusively prove this relationship. In Models 2 to 5, R&D Expenditure has a significantly positive influence on ESG performance, with coefficients ranging from 0.0703 to 0.0820. The significance levels discovered in Models 2 and 3 ($p \leq 0.05$) and Models 4 and 5 ($p \leq 0.10$) highlight the role of research and development in advancing sustainable practices. The findings of Galeotti, Salini, and Verdolini (2020) suggest that increased investments in research and development have a favorable effect on ESG performance by encouraging innovation and energy conservation through stringent environmental regulations. The significant coefficients of R&D Expenditure in most models highlight the importance of research investment in advancing sustainable practices.

Adding control variables improves the explanatory power of the models, as shown by the rise in R-squared values from 0.0184 in Model 1 to 0.0717 in Model 5. GDP per capita consistently has a small but negative and statistically significant coefficient ($p \leq 0.01$), indicating that higher economic development does not always result in improved ESG performance. This is in line with the theory of the Environmental Kuznets Curve, which suggests that environmental deterioration will worsen at first as economic growth occurs, before ultimately getting better (Ekins, 1997).

Government Effectiveness and Population Growth show negative coefficients, but they are not statistically significant in the final model. Regulatory Quality has a negative coefficient, but it is not statistically significant. The negative relationship means that when regulatory quality increases ESG performance typically goes down. This counterintuitive finding indicates that implementing stricter regulations might initially create financial burdens for companies, leading to a potential decrease in their ESG performance in the short run. Nevertheless, it is crucial to recognize that the absence of statistical significance indicates the need to interpret this outcome carefully. Further investigation is needed to examine how the quality of regulations impacts ESG performance, taking into account potential long-term advantages that may not be reflected in short-term evaluations.

5.4 Table V: Fixed Effects Regression Models for Hypothesis 2

The table below displays the Fixed Effects regression models with interaction terms for Hypothesis 2, analyzing the differential impacts of technological advancements on ESG performance in both OECD and non-OECD countries. This consists of the basic interaction model (1) and the complete interaction model (2) including all extra control variables. The results show that patents per billion GDP have a similar influence on both categories, although the positive effects of internet usage and R&D investment are less pronounced in OECD countries, highlighting the impact of the economic context on the success of technological progress. The variables examined include patents per billion GDP, internet usage, R&D spending, GDP per capita, government effectiveness, population growth, and quality of regulations. Every model displays the coefficient estimates with clustered standard errors at the country level in brackets. The significance levels are marked by * (p≤0.1), ** (p≤0.05), and *** (p≤0.01).

Variable	**Baseline Interaction (1)**	**Full Interaction (2)**
Patents per billion GDP	0.0006	0.0006
	(0.67)	(0.80)
Internet Use (% of population)	0.0004	0.0009
	(0.45)	(0.95)
RnD Expenditure (% of GDP)	0.2967***	0.2715***
	(3.09)	(2.85)
OECD * Patents per billion GDP	-0.0001	-0.0005
	(-0.09)	(-0.45)
OECD * Internet Use (% of population)	-0.0019*	-0.0016*
	(-1.91)	(-1.67)
OECD * RnD Expenditure (% of GDP)	-0.2522**	-0.2322**
	(-2.47)	(-2.26)
GDP per capita (const. 2015 US$)		-0.0000*
		(-1.78)
Government Effectiveness		-0.0382
		(-0.78)
Population Growth		-0.0243*
		(-1.72)
Regulatory Quality		-0.0364
		(-1.02)
Constant	-0.0714**	0.0568
	(-2.48)	(0.94)
R^2	0.0936	0.1226

The Fixed Effects models in this table have interaction terms to analyze the varying impact of technological progress on ESG performance in OECD and non-OECD nations. The R-squared value increases from 0.0936 in the basic interaction model to 0.1226 in the expanded interaction model, indicating a better ability to explain outcomes by incorporating control variables and interaction terms. This improvement shows that the model now better understands how technological advancements affect ESG performance in different ways across OECD and non-OECD environments.

The significant R&D Expenditure coefficients in both models (0.2967, $p \leq 0.01$ in Model 1 and 0.2715, $p \leq 0.01$ in Model 2) further support the beneficial impact of R&D investment on ESG performance. However, the negative interaction effect associated with R&D Spending stands out in both Model 1 (-0.2522, $p \leq 0.05$) and Model 2 (-0.2322, $p \leq 0.05$), suggesting that the advantages of R&D spending are more muted in OECD countries compared to non-OECD countries. This indicates that the impact of investing in R&D on ESG performance can vary depending on the economic conditions of the country.

Internet Use is positively related to the models, but the coefficients of 0.0004 in Model 1 and 0.0009 in Model 2 are not statistically significant. The negative and slightly significant effects of interaction terms for Internet Use (-0.0019, $p \leq 0.10$ in Model 1 and -0.0016, $p \leq 0.10$ in Model 2) indicate a weaker positive influence of internet usage on ESG performance in OECD nations. The positive coefficients of Patents per Billion GDP in Models 1 and 2 show no statistical significance (0.0006).

The interaction terms for Patents per Billion GDP show a negative, yet not significant, impact on the ESG performance across OECD and non-OECD countries, suggesting a lack of substantial difference in their influence.

Furthermore, the control variables in the full interaction model provide additional insights: GDP per Capita shows a small negative but marginally significant coefficient (-0.0000, $p \leq 0.10$), supporting the Environmental Kuznets Curve theory that higher economic development does not always lead to improved ESG outcomes (Ekins, 1979). Government Effectiveness has a negative but not statistically significant coefficient (-0.0382). Population Growth shows a negative and marginally significant coefficient (-0.0243, $p \leq 0.10$), suggesting that higher population growth can strain resources and negatively impact ESG outcomes. Regulatory Quality has a negative but not statistically significant coefficient (-0.0364).

The results align with Long & Feng (2024), who found that effective ESG performance significantly reduces greenhouse gas emissions in OECD nations, influenced by strict environmental regulations and technological advancements. However, my research expands this understanding by demonstrating that non-OECD countries benefit more from new technologies, possibly due to lower initial levels of technological adoption and infrastructure.

Galeotti et al. (2020) emphasized the role of strict environmental policies in driving environmental innovation and improving energy efficiency. My findings affirm this by showing that technological progress enhances ESG outcomes, particularly in non-OECD countries where the impact of new technologies is more pronounced due to less established policy frameworks.

Knight and Schor (2014) noted that advanced economies can decouple economic growth from carbon emissions through technological advancement. My results support this, showing that technological progress can enhance ESG performance while maintaining economic growth. However, the decoupling effect is stronger in non-OECD countries, likely due to their lower initial levels of technology.

Freeman and Soete (1997) argue that national technological advancement drives economic and social development. My findings support this, particularly highlighting the significant impact of technological progress in non-OECD countries, where it can accelerate development and improve ESG outcomes.

Porter (1990) highlights how nations achieve competitive advantages through technological innovation. The results show that OECD nations with advanced innovation networks exhibit consistent ESG improvements, while non-OECD nations experience more significant transformations as they adopt new technologies.

Gianfrate and Peri (2019) discuss the benefits of integrating sustainability into financial strategies. My findings demonstrate that technological advancements improve ESG performance in both OECD and non-OECD settings, emphasizing the importance of implementing environmentally friendly technologies globally.

The findings validate Hypothesis 2: The influence of technological progress on ESG performance is more substantial among non-OECD countries than among OECD countries. While patents per billion GDP have a comparable impact in both groups, the benefits of Internet Use and R&D Expenditure are less significant in OECD countries. This indicates that the effectiveness of technological innovations in promoting sustainability is influenced by the economic context, with non-OECD countries experiencing greater enhancements in ESG performance due to their lower initial levels of technological adoption and infrastructure.

CHAPTER 6 Conclusion

In my thesis, I examined how technological progress affects Environmental, Social, and Governance (ESG) outcomes in OECD and non-OECD nations. The study is important because it fills a gap in knowledge regarding the impact of technological innovation on ESG outcomes across different economic settings. Past studies have mainly concentrated on developed countries, creating a lack of comprehension regarding the workings in countries with lower incomes. So, the main inquiry of this thesis is: What is the impact of technological progress on ESG performance in nations at different levels of economic development?

Panel regressions were used to examine data from 93 countries between 1995 and 2020 in order to address the research question. The research looked at patents per billion GDP, internet usage, and R&D expenditure as measures of technological progress. The results from the Fixed Effects models with clustered standard errors showed that these technological factors had a beneficial effect on ESG performance in both OECD and non-OECD nations. More precisely, there was a positive correlation between enhanced ESG scores and all three measures of technological advancement, patents per billion GDP, internet usage, and R&D expenditure. However, the interaction terms showed significant results mainly for R&D spending, indicating that the benefits of R&D spending were more pronounced in non-OECD nations compared to OECD nations.

This research has offered numerous important findings regarding the connection between technological progress and ESG outcomes. The initial observation is that there is a direct relationship between the number of patents per billion GDP and ESG scores, suggesting that innovation plays a role in advancing sustainability. The level of this impact remains similar in OECD and non-OECD nations, highlighting the global advantage of technological progress. In addition, it was discovered that internet usage positively influenced ESG performance, but the results were not statistically significant, suggesting a less robust impact.

Investment in research and development showed a significant positive effect on ESG results, especially in non-OECD nations. The findings indicated that non-OECD countries saw a more substantial improvement in ESG scores with an increase in R&D expenditure compared to OECD nations. This emphasizes the importance of promoting research and innovation in underdeveloped areas to support sustainable progress.

Additionally, the research showed that although GDP per capita was inversely related to ESG performance, this connection supports the theory of the Environmental Kuznets Curve, indicating that environmental deterioration worsens initially as the economy grows before improving at higher income levels. Moreover, effective governance and regulatory excellence, although not always statistically significant, were key elements in improving ESG results, highlighting the importance of strong institutional structures.

Overall, the research shows that advancements in technology enhance ESG outcomes worldwide, especially in non-OECD nations. These results highlight how focused technological investments and policies can promote sustainable development, particularly in poorer areas.

The implications of this study are significant for policymakers and investors. For policymakers, the results highlight the importance of promoting technological innovation with supportive policies, particularly in non-OECD countries where the advantages are greater. The research emphasizes the opportunity for investors to invest in technologies that improve ESG performance, offering sustainable investment possibilities in developing economies. Furthermore, the research lays the groundwork for future studies to delve deeper into the ways in which technological progress can be used to improve ESG results on a worldwide scale.

A main drawback of this research is the limited coverage of the dataset, encompassing information from 93 nations spanning from 1995 to 2020. Although this period offers a thorough review, it might not encompass the latest trends and technological advances after 2020. The data availability was limited by how countries reported information, and there could be missing data due to inconsistent reporting by some countries. Furthermore, acquiring more detailed information or data from more countries, especially smaller or less economically important ones, was not feasible within the limitations of this study.

The research utilized Fixed Effects (FE) models to examine the data, a strong approach that may not completely deal with potential endogeneity concerns like the reverse causality of ESG performance and technological progress. The decision on which proxies to use for measuring technological progress, such as patents per billion GDP, internet usage, and R&D expenditure, was based on the data's availability and reliability across different countries and time periods. These indicators, though commonly used, might not encompass every aspect of technological advancement, like enhancements in quality or the wider societal effects of technology. To overcome these constraints, additional extensive and intricate data would be needed, but such information was beyond the reach of this research.

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APPENDIX A Table VI: Summary of Key Studies

This table offers a brief summary of the main articles examined in the theoretical framework of this study. Every entry contains the article's title, the authors, the publication date, the unit of analysis, the relationship or method examined, and the findings. This organized overview aims to emphasize the important impacts of each research on the correlation between technological progress, financial expansion, ecological preservation, and ethical obligations.

Title	Author(s)	Date	Unit of Analysis	Relationship Tested/Method used	Obtained Results
Capitalism, Socialism, and Democracy	W. S. Carpenter	1943	Economic Systems	Analysis of capitalism, socialism, and democracy; concept of "creative destruction."	Predicts capitalism's evolution to socialism; roles of democratic institutions discussed.
Technical Change and the Aggregate Production Function	R. M. Solow	1957	Aggregate Production Function	Examines the impact of technical change on economic growth; uses production function analysis.	Finds that technical change significantly contributes to economic growth, beyond capital and labor inputs.
Technology and the Pursuit of Economic Growth	D. C. Mowery & N. Rosenberg	1989	National Economies	Explores how technological innovation drives economic growth; qualitative and historical analysis.	Demonstrates that technology is a key driver of economic development, shaping productivity and growth patterns.

Title	Author(s)	Date	Unit of Analysis	Relationship Tested/Method used	Obtained Results
The Competitive Advantage of Nations	M. E. Porter	1990	National Economies	Investigates how nations achieve economic success; introduces the "diamond model" of competitive advantage.	Identifies factors that contribute to national competitive advantage, emphasizing innovation, factor conditions, demand conditions, related and supporting industries, and firm strategy.
Patent Statistics as Economic Indicators: A Survey	Z. Griliches	1990	Patent Statistics	Surveys the use of patent statistics as indicators of economic activity; quantitative analysis.	Concludes that patent data is a useful measure of innovation and technological progress, correlating with economic growth.
The Economics of Industrial Innovation	C. Freeman & L. Soete	1997	Industrial Innovation	Examines the role of innovation in industrial development; uses case studies and empirical analysis.	Highlights the importance of technological innovation in driving industrial growth and economic development.

Title	Author(s)	Date	Unit of Analysis	Relationship Tested/Method used	Obtained Results
The Kuznets Curve for the Environment and Economic Growth: Examining the Evidence	P. Ekins	1997	Economic Growth and Environmental Quality	Investigates the environmental Kuznets curve hypothesis; uses empirical analysis of environmental and economic data.	Finds mixed evidence for the Kuznets curve, indicating that environmental quality initially worsens with economic growth but improves at higher income levels.
The Determinants of National Innovative Capacity	J. L. Furman, M. E. Porter, & S. Stern	2002	National Innovative Capacity	Identifies factors influencing a country's capacity to innovate; empirical analysis using cross-national data.	Highlights the importance of strong R&D investment, educational systems, and economic openness in fostering national innovation.
R&D, Innovation, and Economic Growth: An Empirical Analysis	H. Ulku	2004	R&D and Economic Growth	Empirical analysis of the impact of R&D on innovation and economic growth; uses cross-country data.	Finds that higher R&D investment is associated with significant increases in innovation and economic growth.
Unraveling Socially Responsible Investment Law: Regulating the Unseen Polluters	M. Ronquest	2008	Socially Responsible Investment Law	Reviews the book by Benjamin J. Richardson; discusses legal frameworks for regulating socially responsible investments and unseen polluters.	Highlights the importance of legal structures in promoting socially responsible investment and addressing environmental issues.

Title	Author(s)	Date	Unit of Analysis	Relationship Tested/Method used	Obtained Results
The New Political Role of Business in a Globalized World: A Review of a New Perspective on CSR and Its Implications for the Firm, Governance, and Democracy	A. G. Scherer & G. Palazzo	2011	Corporate Social Responsibility (CSR)	Reviews the evolving political role of businesses in globalization; explores implications of CSR for firms, governance, and democracy through theoretical analysis.	Concludes that businesses play an increasing political role in global governance, with significant implications for CSR, corporate strategies, and democratic processes.
Broadband Infrastructure and Economic Growth	N. Czernich, O. Falck, T. Kretschmer, & L. Woessmann	2011	Broadband Infrastructure	Analyzes the impact of broadband infrastructure on economic growth; uses empirical data from OECD countries.	Finds that broadband infrastructure significantly contributes to economic growth, with higher broadband penetration leading to increased GDP growth rates.
Economic Growth and Climate Change: A Cross-National Analysis of Territorial and Consumption-Based Carbon Emissions in High-Income Countries	K. W. Knight & J. B. Schor	2014	Carbon Emissions in High-Income Countries	Cross-national analysis of the relationship between economic growth and carbon emissions; compares territorial and consumption-based emissions.	Finds that high-income countries exhibit different patterns in territorial versus consumption-based emissions, with economic growth affecting both types of emissions differently.

Title	Author(s)	Date	Unit of Analysis	Relationship Tested/Method used	Obtained Results
Sustainable Development and Financial Markets	T. Busch, R. Bauer, & M. Orlitzky	2015	Financial Markets and Sustainability	Investigates the relationship between sustainable development practices and financial market performance; uses empirical and theoretical analysis.	Concludes that integrating sustainable development into financial market strategies can enhance financial performance and long-term value creation.
Exploring Social Origins in the Construction of ESG Measures	R. G. Eccles & J. Stroehle	2018	ESG Measures	Examines the social origins and influences on the construction of Environmental, Social, and Governance (ESG) metrics; uses qualitative analysis.	Finds that ESG measures are significantly shaped by social contexts and institutional frameworks, affecting their reliability and comparability.
The Green Advantage: Exploring the Convenience of Issuing Green Bonds	G. Gianfrate & M. Peri	2019	Green Bonds	Investigates the benefits and feasibility of issuing green bonds; uses empirical analysis of market data.	Finds that issuing green bonds can offer financial and reputational advantages, such as lower financing costs and enhanced investor appeal.
Internet of Things is a Revolutionary Approach for Future Technology Enhancement: A Review	S. Kumar, P. Tiwari, & M. Zymbler	2019	Internet of Things (IoT)	Reviews the potential of IoT for technological advancements; synthesizes existing research and technological applications.	Highlights that IoT significantly enhances technological capabilities across various industries, offering improved efficiency and innovation potential.

Title	Author(s)	Date	Unit of Analysis	Relationship Tested/Method used	Obtained Results
Measuring Environmental Policy Stringency: Approaches, Validity, and Impact on Environmental Innovation and Energy Efficiency	M. Galeotti, S. Salini, & E. Verdolini	2020	Environmental Policy Stringency	Examines different approaches to measuring the stringency of environmental policies; assesses their validity and impact on environmental innovation and energy efficiency using empirical analysis.	Finds that stringent environmental policies positively influence environmental innovation and improve energy efficiency, but the effectiveness varies by policy type and context.
The Global Innovation Index 2020: Who Will Finance Innovation?	Cornell University, INSEAD, & World Intellectual Property Organization	2020	Global Innovation	Assesses global innovation capacity and financing; uses comprehensive data analysis from multiple countries and sectors.	Highlights disparities in innovation financing across regions and emphasizes the need for increased investment in innovation, particularly in developing economies.
ESG Metrics and Social Equity: Investigating Commensurability	A. R. Keeley, A. J. Chapman, K. Yoshida, J. Xie, J. Imbulana, S. Takeda, & S. Managi	2022	ESG Metrics and Social Equity	Examines the compatibility of ESG metrics with social equity; uses qualitative and quantitative analysis.	Finds that while ESG metrics are essential for sustainability assessments, there are challenges in aligning these metrics with social equity considerations.

Title	Author(s)	Date	Unit of Analysis	Relationship Tested/Method used	Obtained Results
A Systematic Literature Review on ESG During the COVID-19 Pandemic	R. Savio, E. D’Andrassi, & F. Ventimiglia	2023	ESG Performance During COVID-19	Conducts a systematic review of literature on the impact of the COVID-19 pandemic on Environmental, Social, and Governance (ESG) practices; synthesizes findings from various studies.	Concludes that the pandemic has both challenged and reinforced the importance of ESG principles, highlighting the need for resilient and sustainable business practices.
Organizational Digital Transformation: From Evolution to Future Trends	E. J. Omol	2023	Organizational Digital Transformation	Analyzes the evolution and future trends of digital transformation in organizations; uses case studies and theoretical frameworks.	Identifies key phases and future directions of digital transformation, highlighting the importance of adaptive strategies and technological advancements.
What are ESG Metrics? Top ESG Metrics to Know	Quantive	2023	ESG Metrics	Explores the key metrics used to evaluate Environmental, Social, and Governance (ESG) performance; provides an overview and practical guide.	Identifies and explains the importance of various ESG metrics, emphasizing their role in assessing company sustainability and ethical impact.

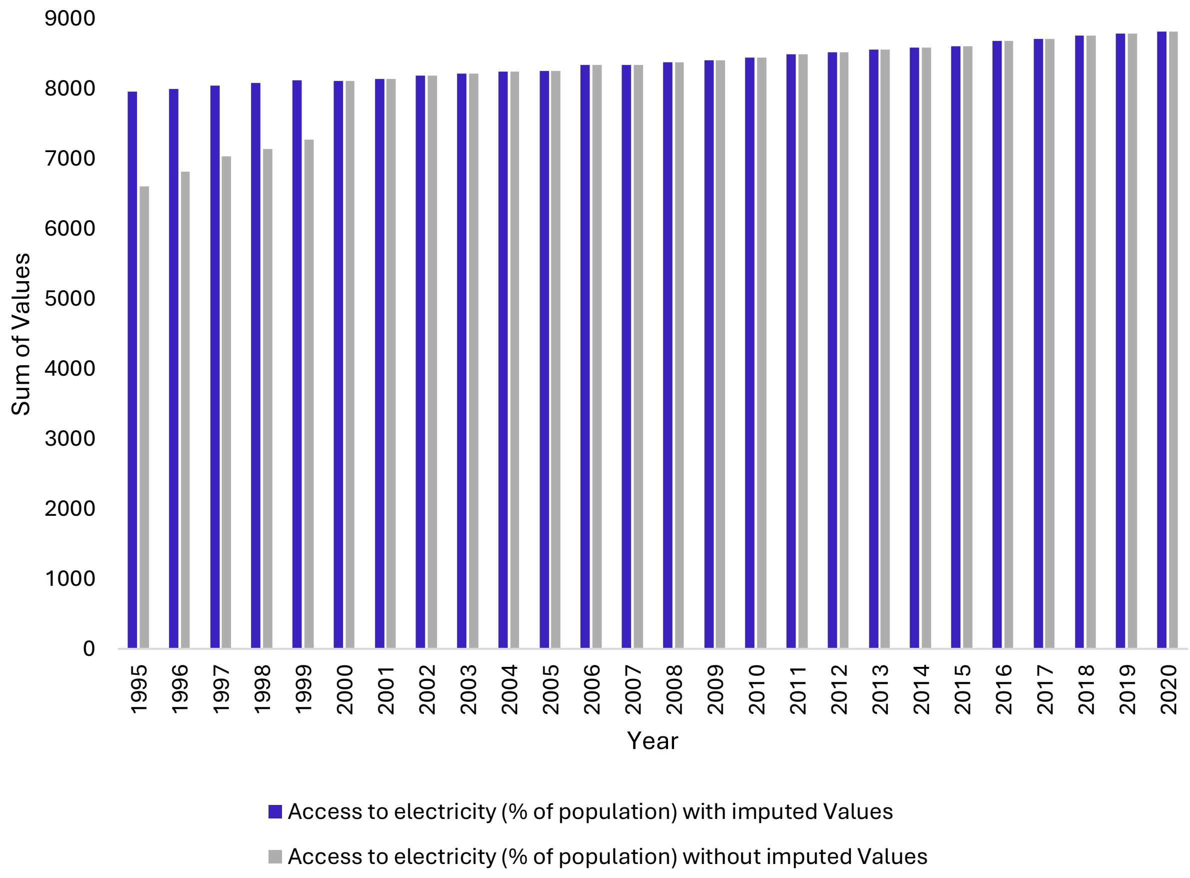
Title	Author(s)	Date	Unit of Analysis	Relationship Tested/Method used	Obtained Results
Global Tech Solutions Can Solve Nearly 50% of the UN Sustainable Development Goals, New Force for Good Report Says	M. Bird	2024, January 9	Technological Solutions for Sustainable Development Goals (SDGs)	Analyzes the potential of global tech solutions to address UN SDGs; uses data and findings from a new report by Force for Good.	Concludes that nearly 50% of the UN SDGs can be addressed through innovative tech solutions, highlighting the critical role of technology in sustainable development.
Does National ESG Performance Curb Greenhouse Gas Emissions?	H. Long & G. Feng	2024	National ESG Performance	Investigates the relationship between national ESG performance and greenhouse gas emissions; uses empirical data analysis.	Finds that stronger national ESG performance is associated with lower greenhouse gas emissions, indicating the effectiveness of ESG measures in reducing environmental impact.

APPENDIX B Comparison of Datasets with and without Forecasted Values

This appendix offers a thorough comparison of three essential variables with and without the imputed values. The data provided demonstrates the total values for all countries in each year, emphasizing how imputation affects the completeness and strength of the dataset.

Figure I: Dataset: Sum of Access to Electricity (% of Population)

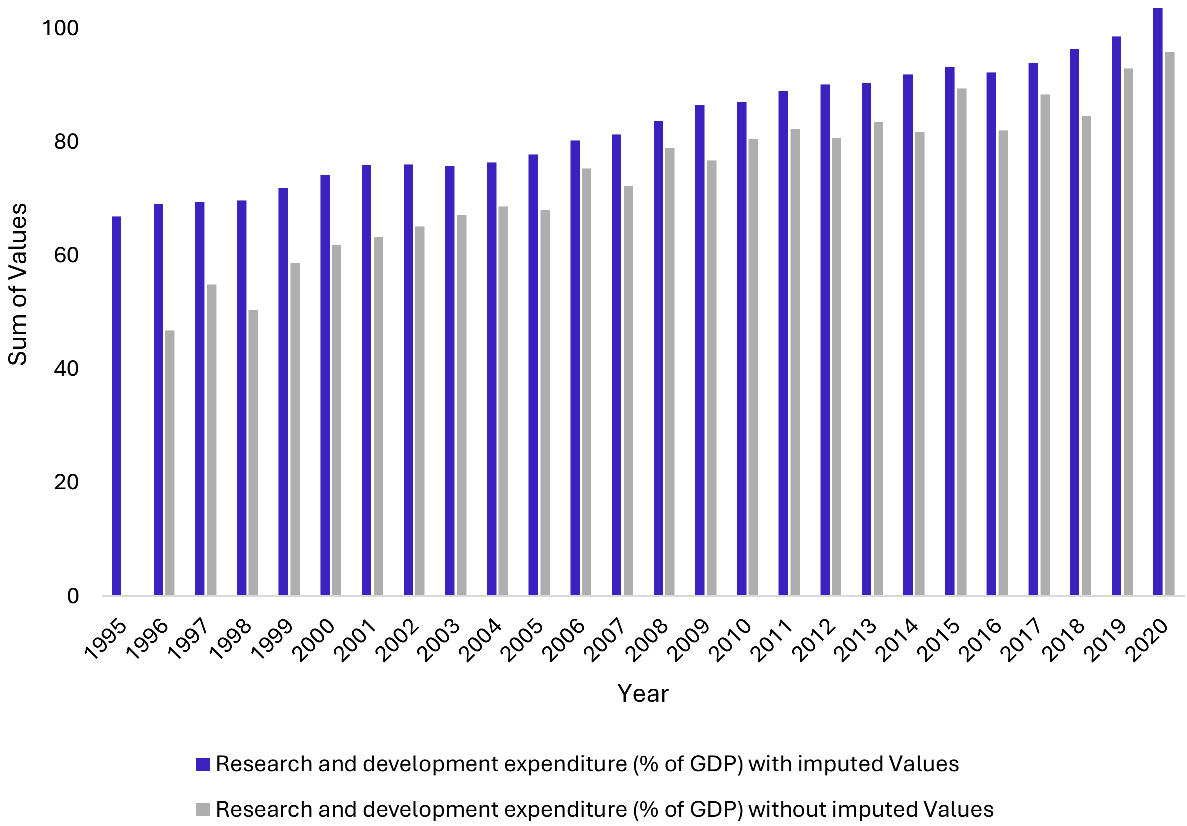
This figure displays the total Access to electricity (% of population) values including imputed values (blue bars) and excluding imputed values (grey bars), representing the cumulative percentages for each year across all countries.



From 1995 to 1999, the total percentages are significantly lower in the dataset excluding the forecasted values. Not all data was documented and accessible at that time. Nonetheless, upon examining the graph representing the total percentages with the imputed values, we notice a steady, gradually rising pattern throughout all years, including the early years. This is logical because the forecasting technique accounts for the data gaps in the initial years (1995-1999).

Figure II: Dataset: Sum of Research and Development Expenditure (% of GDP)

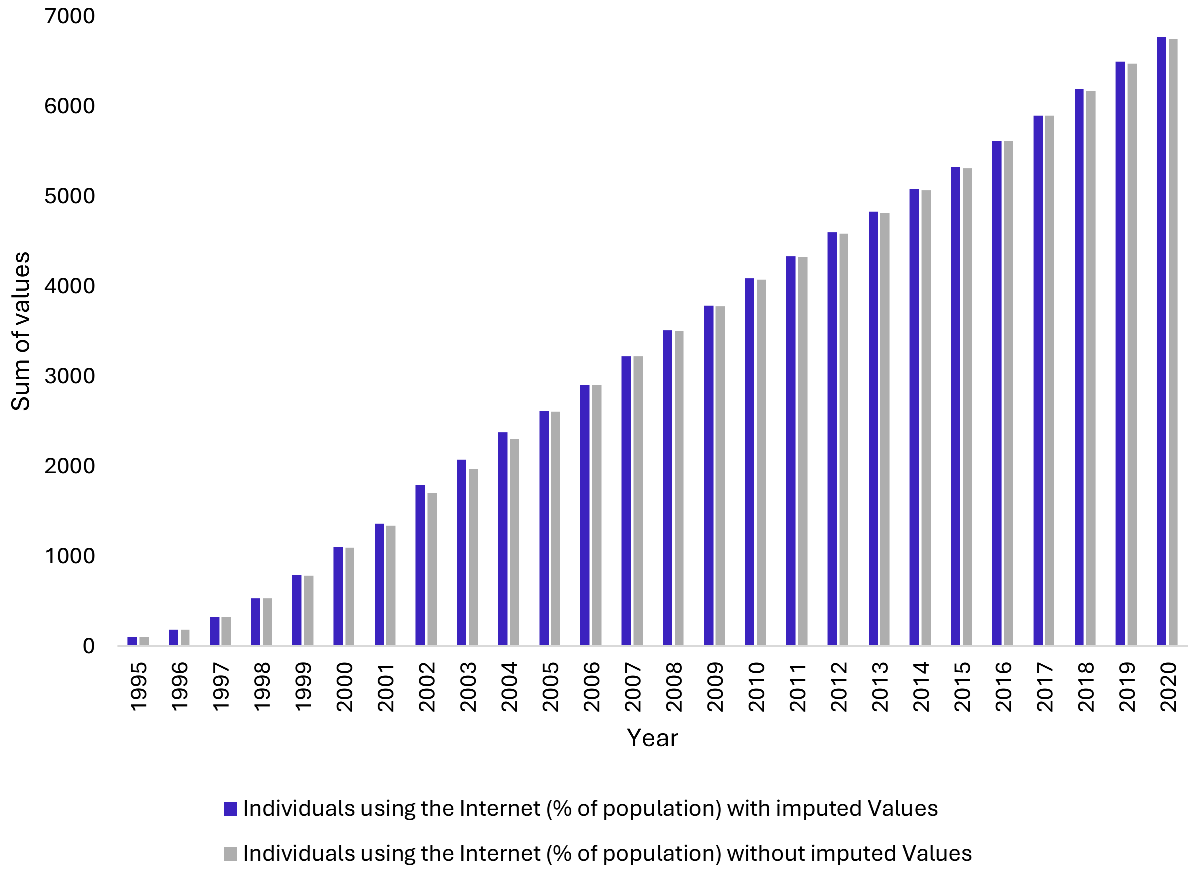
This figure displays the Sum of Research and development expenditure (% of GDP) values with imputed values (blue bars) and without imputed values (grey bars), showing the sum of all percentages across all countries for each year.



It is apparent that in every year, the sum of values are slightly greater in the dataset that includes imputed values, as the dataset without the predicted values simply has fewer values. Nonetheless, both sets of data exhibit a comparable trend, suggesting that the predicted values were accurately estimated. This supports the use of this forecasting method for this dataset to ensure completeness and robustness in the analysis. This method for estimating missing values is especially reasonable for data regarding research and development expenditure as a percentage of GDP. It is important to mention that there was no data available for any country for this variable in 1995. However, in order to include this year in the panel regression, it was predicted based on the trend seen in the following years.

Figure III: Sum of Individuals Using the Internet (% of Population)

This figure shows the Sum of Individuals using the Internet (% of population) values with imputed values (blue bars) and without imputed values (grey bars), showing the sum of all percentages across all countries for each year.



Again, it is evident that the total percentages are slightly greater each year in the dataset with the forecasted values because of the absence of imputed values in the dataset with the missing values. However, both sets of data exhibit a consistent pattern over time, once again, indicating the validity of the forecasting technique to ensure completeness and robustness.