**OECONOMIA**
**COPERNICANA**

**VOLUME 14 ISSUE 3 SEPTEMBER 2023**

p-ISSN 2083-1277, e-ISSN 2353-1827
www.oeconomia.pl

ORIGINAL ARTICLE

**Citation:** Fu, Q., Zhao, X., & Chang, C.-P. (2023). Does ESG performance bring to enterprises' green innovation? Yes, evidence from 118 countries. *Oeconomia Copernicana, 14*(3), 795–832. doi: 10.24136/oc.2023.024

Contact to corresponding author: Chun-Ping Chang, cpchang@g2.usc.edu.tw

Article history: Received: 27.05.2023; Accepted: 21.08.2023; Published online: 30.09.2023

**Qiang Fu**
*Changsha University of Science and Technology, China*
*orcid.org/0000-0003-4118-6860*

**Xinxin Zhao**
*Xi'an Jiaotong University, China*
*orcid.org/0000-0001-7150-2313*

**Chun-Ping Chang**
*Shih Chien University, Taivan*
*orcid.org/0000-0003-1782-4551*

# Does ESG performance bring to enterprises' green innovation? Yes, evidence from 118 countries

**JEL Classification:** *C50; G30; O30*

**Keywords:** *environment, society, and governance (ESG); Green innovation; Sustainable development*

**Abstract**

**Research background:** The sustainable development and innovation economics theory and related literature place a lot of emphasis on the relationship between environment, society, and governance (ESG) and green innovation.
**Purpose of the article:** The purpose of this paper is to understand what the factors are that influence green innovation and why there is a big disparity in green innovation capabilities

between nations. In addition, this paper aims to investigate the impact of ESG performance of green innovation by using unbalanced panel data covering 118 sample countries during the period of 1999–2019.
**Methods:** Panel fixed effect model; Instrumental variable (IV) method; First-differencing (FD) method; Kinky least-squares (KLS) approach.
**Findings & value added:** ESG performance provides evidence for its positive and significant impact on such innovation. Among the ESG factors, governance seems to have the most important influence on green innovation. Moreover, the positive influence of ESG performance is more evident in higher income and wealthy nations. Furthermore, we also conclude that ESG performance can affect green innovation through FDI, human capital, financial development and trade openness. These conclusions hold up after a number of robustness tests and taking into account any potential endogenous issues. Overall, policymakers should pay close attention to the findings.

## Introduction

The ecosystem has been significantly harmed in recent years by an increase in accidents involving environmental contamination. The increasing environmental expenses brought on by economic development are putting greater pressure than ever on environmental pollution control. It is crucial to figure out how to enhance environmental excellence while fostering enduring economic expansion (Wu & Flynn, 1999; Hao *et al.*, 2021). Although environmental degradation is a side effect of economic development, it is not a good idea to prioritize environmental protection at the expense of other benefits. Focusing on environmental advantages while advancing the economy is fraught with challenges. Long-term green economic development can be attained primarily through the innovation of green technologies, even while some actions can reduce pollutant emissions in the near term and accomplish the goal of environmental protection (Feng *et al.*, 2021; Du *et al.*, 2021; Hsu *et al.*, 2021). Therefore, it is crucial to understand what the factors are that influence green innovation and why there is a big disparity in green innovation capabilities between nations.

The key enterprise elements influencing green innovation, according to the literature currently available, are R&D investment, trade openness, and human capital (Wen *et al.*, 2022). Environment, society, and governance (ESG) performance, as a comprehensive index for multi-dimensional evaluation of enterprise management sustainability, plays an important role in green innovation that cannot be ignored (Wang *et al.*, 2023). ESG is a significant standard that the global society uses to assess how sustainable an organization is. The core conceptual framework of ESG includes three major issues: corporate governance, social responsibility, and environmental performance. The subsequent levels have different dimensions and specific indicators depending on the attribute and field of the enterprise. The research related to ESG performance mainly focuses on its relationship with market characteristics, firm leadership characteristics, firm ownership characteristics, firm risk, and firm performance and value. Long *et al.* (2023) has pioneered the use of quantile regression to analyze the impact of national ESG performance on green innovation. However, the sample size in their study was only 37 countries. Under the current global trend of sustainable development, countries are beginning to pay great attention to green innovation technologies. Green innovation should not only be well developed in a few countries, but should be widely applied in all countries of the world, so as to contribute to the improvement of global environmental quality and the realization of green development goals. Thus, the relationship between ESG and green innovation of more countries deserves discussion and consideration, as well as the influence mechanism. With the help of our research, this paper fills the gap in the literature.

According to our deduction, ESG performance may affect green innovation in the following ways. First of all, research and development (R&D) investment has a strong positive link with green innovation activities (Shi & Yang, 2022), while nations with good ESG scores will draw more funding for R&D investment. The level of green innovation will be improved due to the technology spillover effect caused by domestic scientific and technological progress due to the multidimensional R&D investment; Second, countries with better political environment have higher ESG scores due to the low corruption and more willing to disclose ESG information (Hoang, 2022). Meanwhile, the occurrence of internal and external political risks such as corruption and international sanctions will reduce their green innovation activities because of loose environmental regulations, weak response of government environmental policies to citizens' preferences and negative environmental awareness (Fu *et al*., 2022). Third, financial markets are experiencing a significant trend toward sustainable development, and ESG investment is a key component of this movement (Hastalona & Sadalia, 2021). The financial market will receive signals from strong ESG performance to encourage additional ESG investment, and this will positively affect the expansion of green innovation. A robust financial market will also create a favorable business climate, and businesses will have easier access to finance and information, which is also helpful for the growth of green innovation; Finally, democracy could improve economic freedom and protection of property rights, promote the establishment of technological innovation and Intellectual property rights protection institution, which is essential for the emergence and application of new technologies.

In the following ways, our work adds to the body of knowledge already available. First, to the best of our understanding, it is a pioneer in testing the influence of ESG performance on green innovation using large sample data. Using unbalanced panel data covering 118 countries from 1999 to 2019, we analyze the influence of ESG performance on green innovations from a macro-level perspective. Second, we apply the panel fixed-effects model to test the effects of ESG performance on green innovation and find that ESG performance could improve green innovation capability. We further conduct some robustness tests to verify this conclusion, including alternative dependent variables, adding omitted variables, and other methods, which provide policy implications for government policies that enhance green technology capability from the perspective of ESG. Third, based on the results of the nexus between ESG and green innovation, we continued to conduct the subsequent investigation of the potential mechanisms of how ESG affects green innovation. Empirical evidence was used to confirm the existence of these four potential channels of influence paths, including R&D investment, political risk, financial development, and democracy.

This paper's remainder is organized as follows. The prior research on green innovation and ESG performance is arranged in Section 2 first by covering green innovation and then by discussing ESG performance. The variables are discussed in Section 3 along with the methods for doing the empirical research. Section 4 displays the empirical findings of econometric models and runs tests for robustness to verify consistency. The main conclusions of this research are outlined in Section 5.

## Literature review and hypotheses development

Most studies about ESG analyzed its influencing factors, and we find some related literature from a macro perspective. According to Cai *et al.* (2016) and Liang and Renneboog (2017), national characteristics appear to be crucial in explaining a company's ESG/CSR activities. Their findings demonstrate that any cross-national variance is more strongly related to country factors than business features, and that economic development, legislation, and culture all contribute to these variations. Liang and Renneboog (2017) contend that legal origin is the best indicator of a company's adoption and performance of ESG factors. Market characteristic variation within countries is another macro-level factor. Di Giuli and Kostovetsky (2014) provide proof that political slant of the state where its headquarters are located has an effect on a company's ESG performance. ESG scores relate to social capital as well, which is an index that contains three components: vote totals in presidential elections, the percentage of mail-in census responses, and the proportion of associations and non-profits per 10,000 inhabitants are all examples (Jha & Cox, 2015). As the dependent variable of this paper, green innovation has also been found to be one of the factors influencing ESG (Zheng *et al*., 2022). In a word, macro-level characteristics are also significant in determining ESG performance.

There are also some studies in the literature covering the impacts of ESG practices. Tan and Zhu (2022) analyzed how ESG rating at the enterprise level affects green innovation. They proved that ESG rating significantly promotes the quantity and quality of corporate green innovation by easing financial constraints and improving managers' environmental awareness. In addition, stricter environmental regulations and increasingly fierce market competition strengthen the link between ESG rating and green innovation, and the relationship between the two is even closer for companies in the growth stage. Since governance is an important aspect of ESG evaluation, the impact of environmental regulation on green innovation should not be ignored. Of course, we think of Porter's hypothesis that appropriate environmental regulation will stimulate technological innovation, which has also been tested in the literature. Bu *et al.* (2020) proved that ISO14000 environmental management standards will increase innovation input and output, which supports the Porter hypothesis and contributes to green innovation studies. Meanwhile, the Porter hypothesis has also been tested in the relationship between urban environmental legislation and the number of green patents (Zhang *et al*., 2022).

Other factors that could be affected by an ESG rating event are R&D investment, political risk, financial development, and democracy. The research and development of green innovation needs substantial capital investment, as financial support plays a crucial role in it. Companies with high ESG ratings can receive financial support and external capital by disclosing high-quality information, because stakeholders understand corporate social responsibility and long-term sustainable development in addition to corporate governance, management ability, and financial status and are more willing to provide green funds to enterprises (Ahmed *et al*., 2018). Investors tend to show a clear preference for companies with high ESG performance to avoid adverse selection risks and meet their risk-aversion needs (Cornell, 2020; Drempetic *et al*., 2019). Excellent ESG performance can establish a positive social image and enhance a company's reputation, thus increasing the confidence of capital providers in the company and attracting even more R&D investment.

Political volatility may also affect the relationship between ESG and green innovation. Generally, countries or regions with better political environment have higher ESG scores, because high-polluting enterprises have no way to benefit from it, and enterprises are more willing to disclose ESG information (Hoang, 2022). The occurrence of political risks, such as corruption, weakens the responsiveness of government environmental policies to citizens' preferences, generates negative environmental attitudes, and reduces the stringency of environmental regulations (Fu *et al*., 2020). Therefore, in the absence of policy incentives and legal constraints, firms will reduce their green innovation activities. In addition, due to the current tense international situation, external political risks such as international sanctions will also have a negative impact on green innovation (Fu *et al*., 2022).

ESG investment is another key component of the sustainable development trend in financial markets (Hastalona & Sadalia, 2021). ESG ratings are important at correcting the information asymmetry between stakeholders and companies. Good ESG performance can improve the quality of information disclosure, ease the market's concerns about information asymmetry, and help financial institutions better understand corporate information in credit evaluation. The beneficial result is providing green funds for enterprises (Ahmed *et al*., 2018). A well-developed financial market can also enable enterprises to obtain more investment from the capital market and financial institutions, so as to reduce the risk of green innovation caused by the imbalance of capital allocation. The relaxation of financing restrictions provides companies with sufficient funds to carry out technological improvements, energy conservation programs, and other environmental measures to create a virtuous cycle of development (Tan & Zhu, 2022).

It is generally accepted that institutions play an important role in a country's innovation. Democracy tends to promote innovation by respecting individual freedoms, protecting individual rights, and establishing institutions that facilitate technological innovation and protect intellectual property (Wang *et al*., 2021). Mooneeapen *et al*. (2022) provide evidence of the relationship between democracy and ESG. They found that higher corporate ESG performance occurs in countries with lower levels of democracy.

We have also found factors in the literature that can be used as control variables. Open economic markets may attract more foreign investment. The results of Guloglu and Tekin (2012) showed that FDI is significantly positively correlated with green innovation activities, and the improvement of the degree of market opening is beneficial for the flow of green innovation resources, causes fierce competition for green innovation, stimulates the vitality of green innovation, and helps to realize the two-way progress of technological innovation and environmental protection. Scientific researchers are the main implementation subjects of green innovation. The inflow and gathering of scientific research personnel can bring the basic innovation knowledge reserve to the green innovation of enterprises, so as to improve the level of green innovation (Huang *et al*., 2020).

According to the evidence of the relationship between ESG performance and green innovations from the studies noted above, we develop the following hypotheses.

H1: *Strong ESG performance of a country significantly improves green innovation.*

H1a: *National ESG performance promotes green innovation by increasing research and development (R&D) investment.*

H1b: *National ESG performance promotes green innovation by controlling political risk.*

H1c: *National ESG performance promotes green innovation by promoting financial development.*

H1d: *National ESG performance promotes green innovation by improving democracy.*

The common methods in the previous literature used to study the influencing factors of green innovation are Data Envelopment Analysis (DEA) or other related models based on it, such as SBM-DEA and DEA-Tobit (Liu *et al*., 2020; Tang *et al*., 2020; Chen *et al*., 2022). DEA model will not affect the final evaluation results due to the difference of measurement units, and the weight in DEA method is not affected by subjective factors, which is relatively fair. However, DEA can neither measure the negative output nor evaluate the absolute efficiency. DEA is also sensitive to outliers, improper selection of input and output items will affect the accuracy of efficiency evaluation. In addition, it is difficult to make decision suggestions on how to improve inefficiency when using DEA.

In this paper, we will use panel data analysis method, which could solve the problem of missing variables that do not change over time, and provide more information about individual dynamic behavior. In addition, panel data with larger sample size has both cross-section and time dimension, which can improve the accuracy of estimation.

## Variables and method

### *Data source and Variables*

#### Data source

We use annual data for unbalanced panel of 118 nations to examine the influence of ESG on green innovations throughout the years 1999–2019, while taking the availability and integrity of the data into account. Organization for Economic Co-operation and Development (OECD) Statistics are used to compile the data on energy innovation. The World Bank database is where the ESG data is sourced. World Development Indicators provides the data for the other elements, including control variables and potential channel variables (WDI).

#### Dependent variable

*Patent*: Existing studies mostly use two criteria to assess the extent of technological innovation: innovation input and innovation output. R&D investment has typically been used by scholars to gauge a nation's contribution to innovation (Van Beveren & Vandenbussche, 2010). However, the two issues below cannot be avoided when using innovation input to measure innovation. First, not all businesses have straightforward motivations for innovation, as seen by the presence of fake research funds that prevent R&D funding from being used exclusively for innovation. The second problem is that production is not always the result of investment, which makes it impossible to assess the true effectiveness of innovation. The underlying bias of the original data is a common factor in each of these issues. As a result, this study measures the level of innovation using the innovation output indicator of patents (Wen *et al*., 2021). To measure green innovation, we follow Sun *et al*. (2019) and employ patent applications for environmental technology (represented by *Patent*). Climate change mitigation and environmental management technologies can be used to further categorize technologies that are relevant to the environment.

Explanatory variables

*ESG*: As an abbreviation for environmental,[1] social,[2] and governance,[3] ESG is an investment concept that creates enterprise evaluation standards that place more emphasis on these factors than only financial performance: corporate environment, social relations, and governance performance. Sovereign ESG is based on the country, a macroeconomic entity that integrates sustainable development policies and goals to improve the efficiency of global investors in the decision-making process. The sovereign ESG data framework constructed by the World Bank covers three categories of information, environmental, social, and governance, and fully measures the diversity of different countries in terms of environment, policy, and so on. This has helped to improve the quality of sovereign ESG data and to expand the scope and transparency of available data. In addition, the World

[1] Based on a nation's natural resource endowments, management, and replenishment, as well as its resistance to climate change and other natural calamities, environmental categories reflect the sustainability of economic performance. Internalization of environmental externalities brought on by economic activity, access to sustainable energy sources, and food security are all included in this category.

[2] Social categories show how a nation manages basic requirements and poverty reduction, deals with social equality issues, and invests in human capital and productivity to show how sustainable its economic performance is. Indicators of long-term, steady economic growth fall under this category.

[3] Governance category provides sustainability for a country to support long-term stable growth in response to environmental and social risks. This category includes indicators that reflect the power of the nation's judicial, financial, and political systems.

Bank has published continuous ESG data, providing investors with a research basis and practical possibilities.

In order to calculate the generated sovereign ESG index as much as possible, this article refers to the calculation method of Thomson Reuters ESG rating index system to generate the sovereign ESG index of each country. All the 16 themes use percentage rankings to calculate the current year's score,[4] minimizing the impact of country size and disclosure bias, and higher scores indicate a higher level of ESG performance. The weight of the topic is established by dividing the total number of indicators by the number of indicators that make up each theme. For example, the Emissions & Pollution theme contains 5 indicators, the proportion of the indicators is 5/63, and the weight is 7.9%. Finally, the score of ESG is obtained (proxied by *ESG*). Based on the sovereign ESG indicator system given by the World Bank and combined with the importance and availability of indicators, a sovereign ESG indicator system is established in this work, composed of 3 categories, 16 themes, and 63 indicators to comprehensively and objectively measure the level of ESG sovereignty of each country.[5] This appears in Table 1A in the Appendix section.

Other driving factors must to be taken into account in order to conduct a thorough analysis of the growth of the green innovation market. Our study offers a number of control variables that are demonstrated to have an impact on the market for green innovation. The way we measure them is as follows.

(1) *Population*: Population growth and innovation have always interacted over the course of history. It is also true that population expansion has an impact on green innovation. Utilizing each nation's final annual population allows for the control of the population's effect on green innovation, abbreviated as *Population* in this paper.

(2) *Per capita GDP*: A nation's strong economy provides resources for the advancement of technologies relevant to the environment. Economic development is often gauged using gross domestic product per capita. As a result, we adopt the methodology in Wang *et al*. (2019) and use per capita

[4] In order to facilitate the subsequent analysis and validity of the results, the missing values of the indicators are supplemented by the linear interpolation method during data processing.

[5] Based on the principle of variable availability, this paper excludes sample countries with many missing values.

GDP, calculated in constant 2010 US dollars, to reflect the degree of economic growth for the sample countries (proxied by *Per capita GDP*).

(3) *Trade openness*: Trade openness mainly affects green technology innovation through technology spillover effects, competition effects, and innovation cost reduction effects. Therefore, we use the percentage of import and export trade to GDP to represent the trade openness of a country (proxied by *Trade openness*).

(4) *Industry*: In order to support the growth, evolution, and invention of technology, the change in industrial structure will undoubtedly necessitate new technological requirements (Wen *et al*., 2021). Hence, we utilize the ratio of industry added value to GDP to depict industrial structure (proxied by *Industry*).

(5) *Foreign direct investment*: On the one hand, foreign direct investment can reduce the financial limitations faced by a nation's domestic businesses and encourage technical innovation through technology spillovers (Song *et al*., 2015). On the other hand, because of the reliance on multinational corporations for technology, foreign direct investment may potentially limit the pace of domestic technological progress. Therefore, following Zheng *et al.* (2020), the *Foreign direct investment* variable used in this study is calculated as net inflows of foreign direct investment divided by GDP.

(6) *Education level*: It is important to combine education and the development of inventive skills. To support and train more R&D experts for environmental innovation, governments can spend more money overall on education. Additionally, increased educational capacity increases understanding of environmental protection (Fu *et al*., 2020). In our research we thus control for education and utilize the gross secondary enrollment rate as a proxy for education level (proxied by *Education level*). We anticipate this variable to be as positive as possible.

(7) *Population aging*: Population aging has a non-linear effect on green innovation. Before reaching the inflection point, population aging has a positive labor production effect. When the threshold is exceeded, the aging of the population will inhibit the improvement of labor productivity and hinder a nation's level of green innovation. This paper uses population aged 65 and over (% of total population) to measure population aging (proxied by *Population aging*).

*Empirical methodology*

The panel fixed effect model is what we use for the fundamental empirical study. The fixed effects model is widely used in economics to analyze the behavior of economic entities such as firms and countries. It can control the possible influence of individual heterogeneity and the bias caused by possible unobserved variables on the results. In addition, the fixed effects model is also suitable for panel data with relatively large sample size. Thus, we incorporate year-invariant country effects as well as year-invariant country effects into our benchmark model, which is defined as follows:

$$log(\text{ Green innovation}_{it}) = \alpha_0 + \alpha_1 ESG_{it} + \gamma X_{it} + \theta_t + \mu_i + \varepsilon_{it} \quad (1)$$

The dependent variable (*Patent*) is used to measure green innovation; in the empirical analysis, we use *Patent*'s logarithm.; *ESG* is the main independent variable for ESG performance, including environmental, social, and governance; $Z$ is a vector of control variables that include *Population*, *Per capita GDP*, *Trade openness*, *Industry*, *Foreign direct investment*, *Education level*, and *Population aging*; $\mu_i$ is a country's fixed effect variable; $\theta_t$ is the year's fixed effect variable; and $\varepsilon_{i,t}$ represents the error term in the regression model. Standard errors are clustered by country pair. The coefficient of should be noticeably positive, as expected, whereby higher ESG performance means more advanced green innovation.

In addition, by using the mediation effect model, we further conduct the mechanism tests based on the theoretical analysis and hypothesis development. The regression models are as follows:

$$log(\text{ Green innovation}_{it}) = \alpha_0 + \alpha ESG_{it} + \gamma X_{it} + \theta_t + \mu_i + \varepsilon_{it} \quad (2)$$

$$MED_{it} = \alpha_0 + \beta ESG_{it} + \gamma X_{it} + \theta_t + \mu_i + \varepsilon_{it} \quad (3)$$

$$log(\text{ Green innovation}_{it}) = \alpha_0 + \chi ESG_{it} + \delta MED_{it} + \gamma X_{it} + \theta_t + \mu_i + \varepsilon_{it} \quad (4)$$

*MED*$_{it}$ is the mechanism variable. From equation (1), the estimator $\alpha 1$ represents the impact of ESG on the green innovation. Equations (2), (3) and (4) are the test procedures for the mediation effect testing procedures, which can be tested according to the steps of Sobel (1982), Baron and Kenny (1986) and Cole and Maxwell (2003).

First, we test the coefficient $\alpha$. If $\alpha$ is not significant, the mediation effect analysis is terminated. Second, we test the coefficients $\beta$ and $\delta$. If both coefficients are significant, we continue to test $\chi$. If $\chi$ is significant, the mediation effect is significant; if at least one of $\beta$ and $\delta$ is not significant, it is necessary to conduct the Sobel test must be performed. If the test is significant, the mediating effect is significant. If the test is not significant, the mediating effect is not significant.

## Empirical results and discussion

### *Basic results of the impact of ESG performance on green innovation*

The fundamental findings of the effect of ESG performance on green innovation are shown in Table 1. With no other control variables, we just look into the link between *ESG* and *Patent* in column (1). After that, we continue to include more and more control variables from the second column until all of them are included (5), including *Population*, *Per capita GDP*, *Trade openness*, *Industry*, *Foreign direct investment*, *Education level*, and *Population aging*. As a result, we just describe the column's findings (5). At the 1% level, the predicted *ESG* coefficient, which is 5.0533, is significantly positive, demonstrating that ESG performance influences green innovation in a favorable way. However, the P-values of the heteroskedasticity and autoregressive tests are less than 0.1 in each column, indicating that the null hypothesis is rejected. Thus, the current results have heteroscedasticity and autoregressivity problems even though they are significantly positive.

We can use the robust standard error to solve the heteroscedasticity and autocorrelation problems in the regression. In Table 2, we obtain the new results of the fixed effect model with robust standard error. The results show that the coefficients of ESG in all columns remain significantly positive in all columns. The empirical results still prove that ESG performance has a positive impact on green innovation after solving the heteroskedasticity and autocorrelation problems.

This effect is consistent with the results of Long *et al.* (2023), who examine the impact of ESG on green innovation using a sample of 37 countries, implying that the positive impact of ESG performance on green innovation is broadly applicable to most countries in the world.

*Results on how Environment, Society, and Governance have influenced green innovation*

Other than looking into how the overall ESG performance affects green innovation in the fundamental findings, this paper also presents the impact of environmental (proxied by *Environment*), social (proxied by *Society*), and governance (proxied by *Governance*) respectively and also which one has the most positive effects on green innovation. The empirical findings when *Environment* is the most independent variable are listed in Column (1) of Table 3. The empirical findings when *Society* is the most independent variable are listed in Column (2) of Table 3. The empirical findings when *Governance* is the most independent variable are listed in Column 3 of Table 3. This paper adds environmental (proxied by *Environment*), social (proxied by *Society*), and governance (proxied by *Governance*) in one equation to further compare which one has the highest effect on green innovation, which is listed in column (4) in Table 3. In this column, we find that among the above three specific indicators related to ESG performance, green innovation is most positively impacted by governance, whereas social factors have little bearing on it. The effect of environmental on green innovation lies in the middle. The results of the three sub-indicators E, S, and G are also mutually supportive with the results of Long *et al*. (2023), indicating that environment and governance are the main factors affecting green innovation in ESG scores.

*Results of different income countries*

After investigating the impact of environmental (proxied by *Environment*), social (proxied by *Society*), and governance (proxied by *Governance*) respectively, this study additionally investigates if there are any variations in how ESG performance affects green innovation across nations with diverse income levels. Thus, we generate the cross-item of income and ESG performance (proxied by *ESG*Income*) to check whether the effect of ESG performance on green innovation varies under different income countries.[6] The results are mainly listed in Table 4. We discover that the *ESG*Income* coefficient is favorable and significant at the 1% level, indicating the impact of ESG performance on green innovation is more pronounced in higher-income countries. In contrast, Long *et al*. (2023) believed that in non-high-

[6] The data and classification of income come from the World Bank.

income countries, the effect of ESG performance on green innovation is more pronounced when innovation capacity is strong. The inconsistency in this result may be due to the difference in sample size.

*Robustness tests*

To ensure the accuracy of our findings, we do a variety of robustness tests. (i) We use alternative dependent variables to further conduct the empirical analysis. (ii) We also add possible omitted variables and use the panel interactive fixed effect model and IV method to address the endogenous issues with the basic regression model.

To start, we use different dependent variables to make sure the main finding still holds true after changing how the variables are measured. Environmental management technologies and climate change mitigation technologies are the two main categories of environment-related technologies. Therefore, we first employ those patent applications related to environmental management technologies to measure green innovation (proxied by *Patent1*) and then use patent applications related to climate change mitigation technologies to measure green innovation (proxied by *Patent2*). The OECD's database of environmental statistics is where the data for these two variables is found. Columns (1) and (2) in Table 5 list the results. When the dependent variables are *Patent1* and *Patent2*, respectively, we find that ESG scores continue to have a large negative impact on green innovation.

Endogeneity issues due to omitted factors may arise in the regression analysis for the impact of ESG performance on green innovation discussed above. More specifically, additional factors, such as financial development and urbanization, may impact green innovation in addition to those that are included in the fundamental trends that affect it. Endogenous issues arise due to leaving these variables out (Feng *et al*., 2021). It is possible to greatly lessen as thoroughly as possible the detrimental effects of omitted variable bias in the empirical analysis by controlling other factors that influence a nation's green innovation. Therefore, for each country we further add GDP growth (proxied by GDP growth), finance development (proxied by *Finance*), government size (proxied by *Size*), urbanization level (proxied by *Urbanization*), and research and development situation (proxied by *R&D*). To further alleviate the endogeneity issue brought on by the factors that were left out, we which are shown in Table 6. After including a few neglected variables that might impact green innovation, we see that the outcomes support the main conclusions.

The panel interactive fixed-effects model has an advantage over the conventional panel fixed-effects model in that it can more accurately represent reality in particular problems. Additionally, it can completely account for an economy's actual multidimensional shocks and the heterogeneity of how various people react to these shocks (Bai, 2009). Therefore, in order to further test the basic regression's findings, the panel interactive fixed-effect model is also used. The results are shown in column (1) of Table 7, where we find that they again support the main conclusions.

There are still certain unobservable elements that impact ESG performance and the development of green technologies, even though the aforementioned robustness test techniques address potential endogeneity issues of the model to the best of their ability. Therefore, the instrumental variable (IV) method is also used in this paper's robustness testing. To produce instrumental variables utilizing exogenous variables and heteroscedasticity, we specifically employ the method in Lewbel (2012). By integrating the product of the exogenous variables less their own mean and the residual of the endogenous variables' regression on other exogenous variables in the econometric model, the specialized approach develops the instrumental variable. The estimated coefficient of ESG is compatible with the fundamental findings, as can be seen from column (2) in Table 7, indicating that ESG performance does promote green innovation of the sample countries.

Clemens *et al*. (2012) believed that the first-order difference method can aptly control the endogeneity caused by reverse causality, and it is more transparent and effective than using weak instrumental variables. Hence, we also use the first-order difference method to conduct the robustness test. The results of the first-differencing (FD) method appear in column (1) in Table 8. In addition, the measurement error is the third source of endogeneity in our research. Sincy our main explanatory variable (proxied by *ESG*) may not be perfectly measured, the kinky least-squares (KLS) approach (Kiviet, 2013; 2022) provides a tool for estimating the regression consistently without external instruments for a given degree of endogeneity. The results of KLS are listed in column (2) of Table 8. From the result, we find after using the KLS method to deal with the possible endogeneity problem caused by reverse causality and measurement error that the results are still robust.

Last but not least, the cross-sectional dependence of panel data models has also drawn significant attention as a result of the expanded use of panel data. Another frequent occurrence is individual correlation brought on by some sort of individual shock. There are relationships between the sample countries in this research as well. The PCSE estimate approach, which Beck and Katz (1995) proposed, successfully addresses the cross-sectional dependence problem. In order to examine the issue of cross-sectional dependence, we first run the panel PCSE model, and the empirical findings are in column (1) of Table 9. We next employ the DK estimator, which applies a non-parametric strategy to achieve a consistent variance and to further establish the validity of our result, because the PCSE estimators do not account for the non-contemporaneous dependency of diverse data cross-sections (Driscoll & Kraay, 1998). Column (2) of Table 9 features a list of this model's outcomes. The aforementioned findings demonstrate that even when cross-sectional dependence is taken into account, our core findings remain solid.

*Potential mechanism*

Even while we can't rule out the possibility of alternative processes, we base our subsequent investigation of the potential mechanisms on how ESG performance may affect green innovation. We outline the four ways that R&D expenditure, political risk, financial development, and democracy are examples of ESG performance that may have an impact on green innovation in the introduction section. This section will use empirical evidence to confirm the existence of the four potential mechanisms and verify our hypotheses H1a-H1d. This paper uses the share of a country's R&D expenditure in GDP to measure the innovation input and is denoted by *R&D*, uses the International Country Risk Guide's (ICRG) overall political risk score to measure political risks (proxied by *Risk*), where the higher the risk score, the lower the risk, uses total private credit extended by the banking sector as a share of GDP to measure financial development (proxied by *Finance*), and uses the quantitative political regime dataset from Bjornskov and Rode (2020) to measure the degree of democratization in a country (proxied by *Democracy*).

Based on the theoretical study, columns (1) to (4) in Table 10 show the effect of ESG performance on mechanical variables, and the coefficients in all columns are significant, which means that the mediation effect analysis is not terminated and we can proceed to the next steps of mediation effect tests. In Table 11, on the other hand, we can see that the coefficients of ESG and mechanical variables are both significant after the inclusion of mechanical variables, indicating that each mechanical variable has an intermediate effect between ESG and green innovation. The estimation results in column (1) confirm that the coefficients of ESG and R&D are positive and significant at the 1% level. Thus, we conclude that R&D investment serves as an important mechanism through which ESG performance influences green innovation. The coefficient of ESG in column (2) is also positive and significant at the 1% level, while Risk is the mechanical variable, indicating that ESG improves green innovation by reducing political risk in the sample countries. Similarly, we can also conclude that the finance and democracy channels are also present. In summary, we can conclude that ESG performance can affect green innovation through R&D, political risk, financial development and democracy.

## Conclusions

The sustainable development and innovation economics theory and related literature place a great deal of emphasis on the relationship between environment, society, and governance (ESG) and green innovation. Hence, the influence of ESG performance on green innovation is examined in this study utilizing unbalanced panel data spanning 118 nations from 1999 to 2019. The results show that the impact of ESG scores on green innovation is both positive and significant, supporting our hypothesis 1. In addition, the governance component appears to have the largest impact on green innovation in the sample countries among the ESG elements. Furthermore, we also conclude that ESG performance can affect green innovation through R&D investment, political risk, financial development, and democracy, which are consistent with the hypotheses 1a to 1d in our paper. The aforementioned conclusions hold up following a number of robustness tests and taking into account any potential endogenous issues. Moreover, the positive influence of ESG performance is more evident in higher income and wealthy nations. This study, which examines the effect of ESG performance on green innovation, advances previous research in the area of the innovation economy. Overall, policymakers should pay close attention to the findings.

According to the significantly positive effects of ESG performance on green innovation, ESG investment, which is an important factor in improving ESG scores and performance, should be taken seriously. Governments and market participants should take the lead in educating more investors about ESG investments and products and continue to boost the influence of ESG investing and advocate for the resolution of issues related to environment, social and corporate governance.

Since the positive impact of governance is the most prominent among three components, countries should step up efforts to improve governance issues. First, governments can intensify reform efforts, improve work efficiency, reduce the occurrence of corruption, and maintain the stability and authority of the government and the law. Governments also need to improve economic conditions, whether it is enterprises or governments, so that they can have a good business environment, sufficient capital investment, and unimpeded access to information. In addition, governments can provide more equal opportunities for women in education and employment, improve their social status and let women play their important and irreplaceable roles in economic and social development.

ESG rating is not limited to one country or one organization, as green economy and sustainable development is a global goal. Due to the different effects of ESG performance on green innovation in different income countries, relatively developed countries and important inter-governmental international economic organizations can help developing countries or low- and middle-income and low-income countries improve their economic conditions to accelerate the economic and social development, which will contribute to the growth of world economy. Also, a new pattern of varied participation should be developed to boost the synergy and coupling between nations and organizations throughout the world in order to improve the ESG performance.

However, the following limitations are found in the research process. First, due to the difficulty of data collection and processing, this paper only selects only the environment-related technology patents (further divided into two subcategories: environmental management and climate change mitigation) in the OECD statistical database of the OECD to represent green innovation as the measurement index. However, there are some other broad categories of environmental technology domains in the OECD statistics, including climate change adaptation technologies and sustainable ocean economy, which can also be considered as the representative of green innovation. Patents in these domains are also of great importance for green economy and sustainable development; Second, this paper has tested the different effects of ESG on green innovation in different income countries, but only used the full sample to conduct the mechanism test. The 118 countries differ in important characteristics such as economic conditions and environmental situation, which may lead to the different influence paths for ESG and green innovation.

Therefore, further studies could consider more environmental technology domains in measuring green innovation, such as climate change adaptation technologies and sustainable ocean economy. The subcategories of these environmental technology domains are also complex and diverse, which could be used for quantitative analysis to help people obtain more comprehensive findings on green innovation and to make suggestions on how to improve green innovation in various fields. In addition, as for the phenomenon that green innovation is affected differently in different income countries is affected variously, 118 sample countries could be grouped to conduct the empirical tests on the influence path of green innovation and analyze the reasons leading to the different impacts based on the mechanism test method and the analysis of different countries. Then we can better judge the different paths of ESG's influence on green innovation in different countries, and make more reasonable policy suggestions on how to develop green innovation in different countries according to the empirical results of each sample mechanism.

**References**

Ahmed, S. U., Ahmed, S. P., & Hasan, I. (2018). Why banks should consider ESG risk factors in bank lending? *Banks and Bank Systems*, *13*(3), 71–80. doi: 10.21511/bbs.13(3).2018.07.

Bai, J. (2009). Panel data models with interactive fixed effects. *Econometrica*, *77*(4), 1229–1279. doi: 10.3982/ECTA6135.

Baron, R. M., & Kenny, D. A. (1986). The moderator–mediator variable distinction in social psychological research: Conceptual, strategic, and statistical considerations. *Journal of Personality and Social Psychology*, *51*(6), 1173. doi: 10.1037/0022-3514.51.6.1173.

Beck, N., & Katz, J. N. (1995). What to do (and not to do) with time-series cross-section data. *American Political Science Review*, *89*(3), 634–647. doi: 10.2307/2082979.

Bu, M. L., Qiao, Z. Z., & Liu, B. B. (2020). Voluntary environmental regulation and firm innovation in China. *Economic Modelling*, *89*, 10–18. doi: 10.1016/j.econmod.2019.12.020.

Cai, Y., Pan, C. H., & Statman, M. (2016). Why do countries matter so much in corporate social performance? *Journal of Corporate Finance*, *41*, 591–609. doi: 10.1016/j.jcorpfin.2016.09.004.

Chen, J. K., Abbas, J., Najam, H., Liu, J. N., Abbas, J. (2022). Green technological innovation, green finance, and financial development and their role in green total factor productivity: Empirical insights from China. *Journal of Cleaner Production*, *382*, 135131. doi: 10.1016/j.jclepro.2022.135131.

Clemens, M. A., Radelet, S., Bhavnani, R. R., & Bazzi, S. (2012). Counting chickens when they hatch: Timing and the effects of aid on growth. *Economic Journal*, *122*(561), 590–617. doi: 10.1111/j.1468-0297.2011.02482.x.

Cornell, B. (2020). ESG preferences, risk and return. *European Financial Management*, *27*(1), 12–19. doi: 10.1111/eufm.12295.

Cole, D. A., & Maxwell, S. E. (2003). Testing mediational models with longitudinal data: Questions and tips in the use of structural equation modeling. *Journal of Abnormal Psychology*, *112*(4), 558. doi: 10.1037/0021-843X.112.4.558.

Di Giuli, A., & Kostovetsky, L. (2014). Are red or blue companies more likely to go green? Politics and corporate social responsibility. *Journal Financial Economics*, *111*(1), 158–180. doi: 10.1016/j.jfineco.2013.10.002.

Drempetic, S., Klein, C., & Zwergel, B. (2019). The influence of firm size on the ESG score: Corporate sustainability ratings under review. *Journal of Business Ethics*, 167, 333–360. doi: 10.1007/s10551-019-04164-1.

Driscoll, J. C., & Kraay, A. C. (1998). Consistent covariance matrix estimation with spatially dependent panel data. *Review of Economics and Statistics*, *80*(4), 549–560. doi: 10.1162/003465398557825.

Du, K., Cheng, Y., & Yao, X. (2021). Environmental regulation, green technology innovation, and industrial structure upgrading: The road to the green transformation of Chinese cities. *Energy Economics*, *98*, 105247. doi: 10.1016/j.eneco.2021.105247.

Feng, Y., Wang, X., & Liang, Z. (2021). How does environmental information disclosure affect economic development and haze pollution in Chinese cities? The mediating role of green technology innovation. *Science of The Total Environment*, *775*, 145811. doi: 10.1016/j.scitotenv.2021.145811.

Fu, Q., Chen, Y. E., Jang, C. L., & Chang, C. P. (2020). The impact of international sanctions on environmental performance. *Science of The Total Environment*, *745*, 141007. doi: 10.1016/j.scitotenv.2020.141007.

Fu, Q., Gong, Q., Zhao, X. X., & Chang, C. P. (2022). The effects of international sanctions on green innovations. *Technological and Economic Development of Economy*, *29*(1), 141–164. doi: 10.3846/tede.2022.17782.

Guloglu, B., Tekin, R. B., & Saridogan E. (2012). Economic determinants of technological progress in G7 countries: A re-examination. *Economics Letters*, *116*(3), 604–608. doi: 10.1016/j.econlet.2012.06.012.

Hao, L. N., Umar, M., Khan, Z., & Ali, W. (2021). Green growth and low carbon emission in G7 countries: How critical the network of environmental taxes, renewable energy and human capital is? *Science of The Total Environment*, *752*, 141853. doi: 10.1016/j.scitotenv.2020.141853.

Hastalona, D., & Sadalia, I. (2021). Literature review ESG and sustainability finance. *Budapest International Research and Critics Institute-Journal*, *4*(3), 3548–3557. doi: 10.33258/birci.v4i3.2122.

Hoang, K. (2022). Silent but deadly: Political corruption and voluntary ESG disclosure in the United States. *Managerial and Decision Economics*, *43*(7), 2775–2793. doi: 10.1002/mde.3562.

Hsu, C. C., Quang-Thanh, N., Chien, F., Li, L., & Mohsin, M. (2021). Evaluating green innovation and performance of financial development: Mediating concerns of environmental regulation. *Environmental Science and Pollution Research*, *28*(40), 57386–57397. doi: 10.1162/REST_a_00227.

Huang, S., Lu, J., Chau, K. Y., & Zheng, H. (2020). Influence of ambidextrous learning on eco-innovation performance of startups: Moderating effect of top management's environmental awareness. *Frontiers in Psychology*, *11*, 1976. doi: 10.3389/fpsyg.2020.01976.

Jha, A., & Cox, J. (2015). Corporate social responsibility and social capital. *Journal of Banking Finance*, 60, 252–270. doi: 10.1016/j.jbankfin.2015.08.003.

Kiviet, J. F. (2013). Identification and inference in a simultaneous equation under alternative information sets and sampling schemes. *Econometrics Journal*, *16*(1), S24–S59. doi: 10.1111/j.1368-423X.2012.00386.x.

Kiviet, J. F. (2023). Instrument-free inference under confined regressor endogeneity and mild regularity. *Econometrics and Statistics*, *25*, 1–22. doi: 10.1016/j.ecosta.2021.12.008.

Lewbel, A. (2012). Using heteroscedasticity to identify and estimate mismeasured and endogenous regressor models. *Journal of Business & Economic Statistics*, *30*(1), 67–80. doi: 10.1080/07350015.2012.643126.

Liang, H., & Renneboog, L. (2017). On the foundations of corporate social responsibility. *Journal of Finance*, *72*(2), 853–910. doi: 10.1111/jofi.12487.

Liu, C. Y., Gao, X. Y., Ma, W. L., & Chen, X. T. (2020). Research on regional differences and influencing factors of green technology innovation efficiency of China's high-tech industry. *Journal of Computational and Applied Mathematics*, *369*, 112597. doi: 10.1016/j.cam.2019.112597.

Long, H., Feng, G. F., Gong, Q., & Chang, C. P. (2023). ESG performance and green innovation: An investigation based on quantile regression. *Business Strategy and the Environment*. Advance online publication. doi: 10.1002/bse.3410.

Mooneeapen, O., Abhayawansa, S., & Khan, N. M. (2022). The influence of the country governance environment on corporate environmental, social and governance (ESG) performance. *Sustainability Accounting Management and Policy Journal*, *13*(4), 953–985. doi: 10.1108/SAMPJ-07-2021-0298.

Shi, Y., & Yang, C. (2022). How does multidimensional R&D investment affect green innovation? Evidence from China. *Frontiers in Psychology*, *13*, 947108. doi: 10.3389/fpsyg.2022.947108.

Sobel, M. E. (1982). Asymptotic confidence intervals for indirect effects in structural equation models. *Sociological Methodology*, *13*, 290–312. doi: 10.2307/270723.

Song, M., Tao, J., & Wang, S. (2015). FDI, technology spillovers and green innovation in China: Analysis based on data envelopment analysis. *Annals of Operations Research, 228*(1), 47–64. doi: 10.1007/s10479-013-1442-0.

Sun, H., Edziah, B. K., Sun, C., & Kporsu, A. K. (2019). Institutional quality, green innovation and energy efficiency. *Energy Policy*, *135*, 111002. doi: 10.1016/j.enpol.2019.111002.

Tan, Y., & Zhu, Z. (2022). The effect of ESG rating events on corporate green innovation in China: The mediating role of financial constraints and managers' environmental awareness. *Technology in Society*, *68*, 101906. doi: 10.1016/j.techsoc.2022.101906.

Tang, K., Qiu, Y., & Zhou, D. (2020). Does command-and-control regulation promote green innovation performance? Evidence from China's industrial enterprises. *Science of the Total Environment*, *712*, 136362. doi: 10.1016/j.scitotenv.2019.136362.

Van Beveren, I., & Vandenbussche, H. (2010). Product and process innovation and firms' decision to export. *Journal of economic policy reform*, *13*(1), 3–24. doi: 10.1080/17487870903546267.

Wang, Q. J., Feng, G. F., Chen, Y. E., Wen, J., & Chang, C. P. (2019). The impacts of government ideology on innovation: What are the main implications? *Research Policy*, *48*(5), 1232–1247. doi: 10.1016/j.respol.2018.12.009.

Wang, Q. J., Feng, G. F., Wang, H. J., & Chang, C. P. (2021). The impacts of democracy on innovation: Revisited evidence. *Technovation*, *108*, 102333. doi: 10.1016/j.technovation.2021.102333.

Wang, Q. J., Wang, H. J., Feng, G. F., & Chang, C. P. (2023). Impact of digital transformation on performance of environment, social, and governance: Empirical evidence from China. *Business Ethics, the Environment & Responsibility*. Advance online publication. doi: 10.1111/beer.12573.

Wen, J., Li, L., Zhao, X., Jiao, C., & Li, W. (2022). How government size expansion can affect green innovation—An empirical analysis of data on cross-country green patent filings. *International Journal of Environmental Research and Public Health*, *19*(12), 7328. doi: 10.3390/ijerph19127328.

Wen, J., Zhao, X. X., & Chang, C. P. (2021). The impact of extreme events on energy price risk. *Energy Economics*, *99*, 105308. doi: 10.1016/j.eneco.2021.105308.

Wu, B., & Flynn, A. (1995). Sustainable development in China: Seeking a balance between economic growth and environmental protection. *Sustainable Development*, *3*(1), 1–8. doi: 10.1002/sd.3460030102.
Zhang, F., Yang, Y. W., Ahmad, M., & Shao, J. J. (2022). Would the urban environmental legislation realize the Porter hypothesis? Empirical evidence based on panel data of Chinese prefecture cities. *Frontiers in Environmental Science*, *10*, 944383. doi: 10.3389/fenvs.2022.944383.
Zheng, J., Khurram, M. U., & Chen, L. (2022). Can green innovation affect ESG ratings and financial performance? Evidence from Chinese GEM listed companies. *Sustainability*, *14*, 8677. doi: 10.3390/su1414867.
Zheng, M., Feng, G. F., Wen, J., & Chang, C. P. (2020). The influence of FDI on domestic innovation: An investigation using structural breaks. *Prague Economic Papers*, *29*(4), 403–423. doi: 10.18267/j.pep.739.

**Acknowledgements**

Qiang Fu acknowledges funding support from General Program of the National Social Science Fund of China "Study on the Benefit Mechanism and Support Policies for Promoting Scale Operation of Agricultural Services (19BJ L030)", the Municipal project "Study on Innovation and Development of Modern Service Industry in Central City" and the project adviser Prof. Peng Xinyu. We are also grateful for helpful comments and suggestions from editor and all anonymous reviewers. We are solely responsible for any errors and omissions.

Ministry of Education and Science
Republic of Poland

The journal is co-financed in the years 2022–2024 by the Ministry of Education and Science of the Republic of Poland in the framework of the ministerial programme "Development of Scientific Journals" (RCN) on the basis of contract no. RCN/SN/0697/2021/1 concluded on 29 September 2022 and being in force until 28 September 2024.

## Annex

**Table 1.** Basic results of the impact of ESG performance on green innovation

| Variable | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| *ESG* | 6.0764*** | 4.0687*** | 5.5695*** | 4.8532*** | 5.0533*** |
| | (35.11) | (19.24) | (13.34) | (4.72) | (4.87) |
| *Population* | | -0.0948 | 0.2220*** | 0.4590* | 0.4833* |
| | | (-1.51) | (3.41) | (1.86) | (1.96) |
| *Per capita GDP* | | 0.0483*** | 0.0564*** | 0.0000 | -0.0019 |
| | | (14.87) | (17.52) | (0.00) | (-0.16) |
| *Trade openness* | | | -12.0735*** | 1.0219 | 0.4511 |
| | | | (-10.57) | (0.70) | (0.30) |
| *Industry* | | | 0.0276 | -0.1928 | -0.0627 |
| | | | (0.04) | (-0.22) | (-0.07) |
| *Foreign direct investment* | | | | -0.7153 | -0.6248 |
| | | | | (-0.78) | (-0.68) |
| *Education level* | | | | 0.0015 | -0.0015 |
| | | | | (0.05) | (-0.05) |
| *Population aging* | | | | | 0.0425 |
| | | | | | (1.45) |
| *Constant* | -0.8944*** | -0.6649*** | -0.6942*** | -0.7366*** | -0.6904*** |
| | (-5.57) | (-4.45) | (-5.00) | (-7.73) | (-6.87) |
| *Country* | Yes | Yes | Yes | Yes | Yes |
| *Year* | Yes | Yes | Yes | Yes | Yes |
| *N* | 1197 | 1197 | 1197 | 1197 | 1197 |
| *Heteroskedasticity test* | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| *Autocorrelation test* | 0.0037 | 0.0352 | 0.0763 | 0.0489 | 0.0603 |
| $R^2$ | 0.5934 | 0.6536 | 0.6968 | 0.4248 | 0.4263 |

Notes: The t-statistics are represented by the values in parentheses. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

**Table 2.** Basic results of the impact of ESG performance on green innovation with robust standard error

| Variable | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| *ESG* | 3.4399*** | 3.4748*** | 3.6090*** | 3.7513*** | 4.2798*** |
| | (2.79) | (2.88) | (3.04) | (3.06) | (3.31) |
| *Population* | | 0.4845*** | 0.4666** | 0.4382** | 0.5104*** |
| | | (2.68) | (2.57) | (2.49) | (2.89) |
| *Per capita GDP* | | 0.0072 | 0.0078 | 0.0065 | 0.0016 |
| | | (0.47) | (0.51) | (0.44) | (0.12) |
| *Trade openness* | | | 0.4682 | 0.4808 | -0.6070 |
| | | | (0.21) | (0.21) | (-0.26) |
| *Industry* | | | -0.5014 | -0.6562 | -0.2407 |
| | | | (-0.57) | (-0.73) | (-0.27) |
| *Foreign direct investment* | | | | -0.7939 | -0.6449 |
| | | | | (-0.48) | (-0.36) |
| *Education level* | | | | -0.0287 | -0.0283 |
| | | | | (-0.71) | (-0.70) |
| *Population aging* | | | | | 0.0820 |
| | | | | | (1.52) |
| *Constant* | -0.8347*** | -0.7995*** | -0.7889*** | -0.8056*** | -0.7093*** |
| | (-8.59) | (-6.68) | (-6.47) | (-6.61) | (-5.29) |
| *Country* | Yes | Yes | Yes | Yes | Yes |
| *Year* | Yes | Yes | Yes | Yes | Yes |
| *N* | 1197 | 1197 | 1197 | 1197 | 1197 |
| $R^2$ | 0.3946 | 0.3977 | 0.3980 | 0.3990 | 0.4045 |

Notes: The t-statistics are represented by the values in parentheses. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

**Table 3.** Results of the impacts of Environment, Society, and Governance on green innovation

| Variable | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| *Environment* | 4.2783** | | | 3.7861** |
| | (2.39) | | | (2.06) |
| *Society* | | 3.1411 | | 2.4532 |
| | | (1.05) | | (0.81) |
| *Governance* | | | 6.8865*** | 6.3790** |
| | | | (2.62) | (2.48) |
| *Population* | 0.5972*** | 0.6551*** | 0.5321*** | 0.4816*** |
| | (3.10) | (3.56) | (2.97) | (2.71) |
| *Per capita GDP* | -0.0003 | -0.0075 | -0.0038 | 0.0020 |
| | (-0.02) | (-0.52) | (-0.28) | (0.14) |
| *Trade openness* | -0.7016 | -0.8505 | -0.7430 | -0.5969 |
| | (-0.28) | (-0.35) | (-0.30) | (-0.25) |
| *Industry* | 0.0743 | 0.4043 | -0.2194 | -0.4071 |
| | (0.08) | (0.43) | (-0.24) | (-0.45) |
| *Foreign direct investment* | -0.6544 | -0.6626 | -0.4303 | -0.5484 |
| | (-0.38) | (-0.36) | (-0.23) | (-0.30) |
| *Education level* | -0.0130 | -0.0206 | -0.0167 | -0.0244 |
| | (-0.33) | (-0.49) | (-0.42) | (-0.58) |
| *Population aging* | 0.0803 | 0.0590 | 0.0640 | 0.0814 |
| | (1.55) | (1.22) | (1.37) | (1.56) |
| *Constant* | -0.7324*** | -0.7727*** | -0.7249*** | -0.6980*** |
| | (-5.54) | (-5.86) | (-5.42) | (-5.22) |
| *Country* | Yes | Yes | Yes | Yes |
| *Year* | Yes | Yes | Yes | Yes |
| *N* | 1197 | 1197 | 1197 | 1197 |
| $R^2$ | 0.3980 | 0.3934 | 0.4003 | 0.4056 |

Notes: (1) This table presents the impact of environmental (proxied by *Environmnet*), social (proxied by *Society*), and governance (proxied by *Governance*) respectively. The empirical findings when *E* is the most independent variable are listed in Column 1. The empirical findings when *S* is the most independent variable are listed in Column 2. The empirical findings when *G* is the most independent variable are listed in Column 3. (2) The t-statistics are represented by the values in parenthesis. *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

**Table 4.** Results of heterogeneity analysis

| Variable | The results of different income countries |
|---|---|
| | (1) |
| *ESG* | 10.7352*** |
| | (3.51) |
| *ESG*Income* | 2.1996** |
| | (2.22) |
| *Population* | 0.4690 |
| | (1.62) |
| *Per capita GDP* | 0.0644*** |
| | (5.36) |
| *Trade openness* | 0.7139 |
| | (0.46) |
| *Industry* | -0.9079 |
| | (-1.01) |
| *Foreign direct investment* | 1.0462 |
| | (1.02) |
| *Education level* | 0.0741** |
| | (2.29) |
| *Population aging* | 0.1607*** |
| | (6.23) |
| *Constant* | 0.2172 |
| | (0.45) |
| *Country* | Yes |
| *Year* | Yes |
| *N* | 945 |
| $R^2$ | 0.2363 |

Notes: (1) This table lists the results when we generate the cross-item of income and ESG performance to check whether the effect of ESG performance on green innovation varies under different income countries. (2) The t-statistics are represented by the values in parenthesis. *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

**Table 5.** Robustness tests: Alternative dependent variables

| Variable | *Patent1* | *Patent2* |
|---|---|---|
| | **(1)** | **(2)** |
| *ESG* | 4.0352** | 3.4408** |
| | (2.01) | (2.34) |
| *Population* | 0.9374*** | 0.6249*** |
| | (5.31) | (3.81) |
| *Per capita GDP* | -0.0306** | -0.0201* |
| | (-2.14) | (-1.77) |
| *Trade openness* | 1.2177 | -0.6548 |
| | (0.47) | (-0.34) |
| *Industry* | -0.2149 | 1.3311 |
| | (-0.13) | (1.14) |
| *Foreign direct investment* | 0.9122 | -0.5780 |
| | (1.18) | (-0.29) |
| *Education level* | -0.0387 | -0.0023 |
| | (-0.61) | (-0.05) |
| *Population aging* | 0.0689 | 0.0079 |
| | (0.94) | (0.18) |
| *Constant* | 1.7458*** | 1.9456*** |
| | (10.32) | (13.27) |
| *Country* | Yes | Yes |
| *Year* | Yes | Yes |
| *N* | 944 | 944 |
| $R^2$ | 0.3080 | 0.5547 |

Notes: (1) This Table lists the results when the dependent variables are *Patent1* and *Patent2* in column 1 and 2 respectively. (2) The t-statistics are represented by the values in parenthesis. *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

**Table 6.** Robustness tests: adding omitted variables

| Variable | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| *ESG* | 4.2781*** | 4.1850*** | 4.7434*** | 4.5718*** | 7.3036*** |
| | (3.31) | (3.26) | (3.48) | (3.43) | (4.11) |
| *Population* | 0.5102*** | 0.4341** | 0.4580** | 0.4648** | 0.5378** |
| | (2.89) | (2.43) | (2.21) | (2.26) | (2.45) |
| *Per capita GDP* | 0.0016 | -0.0020 | 0.0006 | 0.0024 | -0.0063 |
| | (0.11) | (-0.14) | (0.04) | (0.16) | (-0.36) |
| *Trade openness* | -0.6156 | -1.0786 | -1.3786 | -1.1338 | -0.0807 |
| | (-0.26) | (-0.43) | (-0.61) | (-0.51) | (-0.03) |
| *Industry* | -0.2417 | -1.3062 | -1.5931 | -1.6330 | 0.1644 |
| | (-0.27) | (-1.15) | (-1.30) | (-1.33) | (0.07) |
| *Foreign direct investment* | -0.6524 | -0.4606 | -0.0188 | -0.0238 | -0.1637 |
| | (-0.36) | (-0.24) | (-0.01) | (-0.02) | (-0.13) |
| *Education level* | -0.0283 | -0.0202 | -0.0015 | 0.0008 | 0.0271 |
| | (-0.70) | (-0.50) | (-0.04) | (0.02) | (0.58) |
| *Population aging* | 0.0819 | 0.0843 | 0.0852 | 0.0796 | 0.0164 |
| | (1.52) | (1.61) | (1.47) | (1.36) | (0.29) |
| *GDP growth* | 0.0005 | 0.0001 | -0.0002 | -0.0002 | -0.0003 |
| | (0.41) | (0.11) | (-0.17) | (-0.18) | (-0.24) |
| *Size* | | -0.0115* | -0.0119 | -0.0122 | -0.0108 |
| | | (-1.67) | (-1.53) | (-1.56) | (-0.68) |
| *Finance* | | | -0.0008 | -0.0006 | -0.0014 |
| | | | (-0.35) | (-0.29) | (-0.75) |
| *Urbanization* | | | | 0.0101 | 0.0031 |
| | | | | (0.50) | (0.12) |
| *R&D* | | | | | 0.3975*** |
| | | | | | (3.76) |
| *Constant* | -0.7098*** | 0.1933 | 0.2133 | -0.4054 | -0.6358 |
| | (-5.29) | (0.35) | (0.35) | (-0.30) | (-0.28) |
| *Country* | Yes | Yes | Yes | Yes | Yes |
| *Year* | Yes | Yes | Yes | Yes | Yes |
| *N* | 1197 | 1196 | 1122 | 1122 | 820 |
| $R^2$ | 0.4045 | 0.4072 | 0.3957 | 0.3962 | 0.4673 |

Notes: (1) This table lists the results when we further add GDP growth (proxied by GDP growth), government size (proxied by Size), finance development (proxied by Finance), urbanization level (proxied by Urban), and research and development situation (proxied by R&D) to further alleviate the endogeneity issue brought on by the factors that left out in columns 1-4 respectively. (2) The t-statistics are represented by the values in parenthesis. *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

**Table 7.** Robustness tests: other methods

| Variable | Panel interaction fixed effects | IV |
|---|---|---|
| | (1) | (2) |
| *ESG* | 4.0197*** | 4.3084*** |
| | (4.18) | (4.38) |
| *Population* | 0.1859 | 0.5026*** |
| | (0.46) | (3.46) |
| *Per capita GDP* | 0.0041 | 0.0021 |
| | (0.35) | (0.24) |
| *Trade openness* | -1.3233 | -0.5466 |
| | (-0.84) | (-0.34) |
| *Industry* | -0.2377 | -0.2463 |
| | (-0.29) | (-0.31) |
| *Foreign direct investment* | 0.0573 | -0.6371 |
| | (0.05) | (-0.38) |
| *Education level* | 0.0771** | -0.0282 |
| | (2.53) | (-0.90) |
| *Population aging* | 0.0687** | 0.0823*** |
| | (2.15) | (3.10) |
| *Country* | Yes | Yes |
| *Year* | Yes | Yes |
| *N* | 1185 | 1197 |
| $R^2$ | | 0.4043 |

Notes: (1) This table lists the results when we use different methods to deal with the potential endogeneity problems. Column 1 lists the results when we use panel interaction fixed effects model, and column 2 lists the results when we use the instrumental variable (IV) method in Lewbel (2012). (2) The t-statistics are represented by the values in parenthesis. *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

**Table 8.** Robustness tests: other methods for endogeneity problem

| Variable | First differencing (FD) estimator | KLS estimator |
|---|---|---|
| | (1) | (2) |
| *FD.ESG* | 3.2035* | |
| | (1.92) | |
| *ESG* | | 19.6408*** |
| | | (4.57) |
| *FD.Population* | 0.0653 | |
| | (0.16) | |
| *Population* | | 0.2077 |
| | | (0.64) |
| *FD.Per capita GDP* | 0.0123 | |
| | (0.62) | |
| *Per capita GDP* | | 0.0824*** |
| | | (7.00) |
| *FD.Trade openness* | 0.0020 | |
| | (0.57) | |
| *Trade openness* | | 0.0015 |
| | | (0.98) |
| *FD.Industry* | 0.0040 | |
| | (0.23) | |
| *Industry* | | -0.0226** |
| | | (-2.21) |
| *FD.Foreign direct investment* | 0.0029*** | |
| | (2.82) | |
| *Foreign direct investment* | | 0.0003 |
| | | (0.30) |
| *FD.Education* | 0.0143 | |
| | (0.19) | |
| *Education* | | -0.0084 |
| | | (-0.24) |
| *FD.Population aging* | 0.0779 | |
| | (0.54) | |
| *Population aging* | | 0.2577*** |
| | | (9.21) |
| *Country* | Yes | Yes |
| *Year* | Yes | Yes |
| *N* | 931 | 1197 |
| $R^2$ | 0.8625 | |

Notes: (1) This table lists the results when we further use different methods to deal with the potential endogeneity problems. Column 1 lists the results when we use first-differencing estimator, and column 2 lists the results when we use the KLS method. (2) The t-statistics are represented by the values in parenthesis. *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

**Table 9.** Robustness tests: considering the issue of cross-sectional dependence

| Variable | Panel PCSE model | DK estimator |
|---|---|---|
| | (1) | (2) |
| *ESG* | 4.6131*** | 4.2798*** |
| | (4.73) | (4.11) |
| *POP* | 0.5220*** | 0.5104*** |
| | (3.64) | (3.04) |
| *GDP* | 0.0191** | 0.0016 |
| | (2.54) | (0.14) |
| *Openness* | -0.4320 | -0.6070 |
| | (-0.29) | (-0.42) |
| *Industry* | -0.4523 | -0.2407 |
| | (-0.61) | (-0.31) |
| *FDI* | -0.3343 | -0.6449 |
| | (-0.19) | (-0.38) |
| *Edu* | -0.0103 | -0.0283 |
| | (-0.34) | (-0.70) |
| *Aging* | 0.1367*** | 0.0820*** |
| | (5.95) | (5.68) |
| *Constant* | -0.4793*** | 0.2740*** |
| | (-5.48) | (4.62) |
| *Country* | Yes | Yes |
| *Year* | Yes | Yes |
| *N* | 1197 | 1197 |
| $R^2$ | 0.3770 | |

Notes: (1) This table lists the results for dealing with the possible cross-sectional dependence problem. Column 1 lists the results when we use the PCSE estimate approach proposed by Beck and Katz (1995), and column 2 lists the results of DK estimator, which applies a non-parametric strategy to achieve a consistent variance. (2) The t-statistics are represented by the values in parenthesis. *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

**Table 10.** The results of ESG and mechanism variables

| Variable | R&D | Risk | Finance | Democracy |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| *ESG* | 0.3330** | 10.1826*** | 0.1932** | 0.3330** |
| | (2.13) | (5.01) | (2.09) | (2.13) |
| *Constant* | 0.8149*** | 68.0568*** | 0.5039*** | 0.8149*** |
| | (23.40) | (512.03) | (17.90) | (23.40) |
| *Country* | Yes | Yes | Yes | Yes |
| *Year* | Yes | Yes | Yes | Yes |
| *Control variables* | Yes | Yes | Yes | Yes |
| $R^2$ | 0.2274 | 0.0777 | 0.0261 | 0.7397 |
| *F* | 11.5953 | 15.5615 | 1.2731 | 52.1068 |

Notes: This table lists the results of the impact of ESG on mechanism variables. Column 1 lists the results of the impact of ESG on the *R&D* channel, column 2 lists the results of the impact of ESG on the Risk channel, column 3 lists the results of the impact of ESG on the Finance channel, and column 4 lists the results of the impact of ESG on the Democracy channel. (2) The t-statistics are represented by the values in parentheses. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

**Table 11.** The results of ESG, mechanical variables and green innovation

| Variable | R&D | Risk | Finance | Democracy |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| *ESG* | 4.1823*** | 4.9341*** | 4.6925*** | 3.9025*** |
| | (4.02) | (5.08) | (6.55) | (5.65) |
| *R&D* | 0.4048*** | | | |
| | (4.12) | | | |
| *Risk* | | 0.0103* | | |
| | | (1.78) | | |
| *Finance* | | | 0.0068*** | |
| | | | (8.25) | |
| *Democracy* | | | | 0.2819*** |
| | | | | (2.96) |
| *Constant* | -1.3115*** | -1.5796*** | -1.0496*** | -0.9198*** |
| | (-8.66) | (-3.52) | (-4.13) | (-4.19) |

**Table 11.** Continued

| Variable | R&D | Risk | Finance | Democracy |
|---|---|---|---|---|
| | **(1)** | **(2)** | **(3)** | **(4)** |
| *Country* | Yes | Yes | Yes | Yes |
| *Year* | Yes | Yes | Yes | Yes |
| *Control variables* | Yes | Yes | Yes | Yes |
| $R^2$ | 0.4535 | 0.4532 | 0.5496 | 0.5080 |
| $F$ | 25.1195 | 27.2964 | 37.8487 | 38.4633 |

Notes: This table lists the possible channels through which ESG can have a significant impact on green innovation. Column 1 lists the results when we add ESG and R&D channel together in the regression model, column 2 lists the results when we add ESG and Risk channel together in the regression model, column 3 lists the results when we add ESG and Finance channel together in the regression model. Column 4 lists the results when we add ESG and Democracy channels together in the regression model. (2) The t-statistics are represented by the values in parentheses. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

# Appendix

**Table 1A.** Sovereign ESG evaluation index system

| Category | Theme | Series |
|---|---|---|
| Environment Pillar（27） | Emissions & pollution (5) | CO2 emissions (metric tons per capita) |
| | | GHG net emissions/removal by LUCF (Mt of CO2 equivalent) |
| | | Methane emissions (metric tons of CO2 equivalent per capita) |
| | | Nitrous oxide emissions (metric tons of CO2 equivalent per capita) |
| | | PM2.5 air pollution, mean annual exposure (micrograms per cubic meter) |
| | Natural capital endowment & management (6) | Adjusted savings: natural resources depletion (% of GNI) |
| | | Adjusted savings: net forest depletion (% of GNI) |
| | | Annual freshwater withdrawals, total (% of internal resources) |
| | | Forest area (% of land area) |
| | | Mammal species, threatened |
| | | Terrestrial and marine protected areas (% of total territorial area) |
| | Energy use & security (7) | Electricity production from coal sources (% of total) |
| | | Energy imports, net (% of energy use) |
| | | Energy intensity level of primary energy (MJ/$2017 PPP GDP) |
| | | Energy use (kg of oil equivalent per capita) |
| | | Fossil fuel energy consumption (% of total) |
| | | Renewable electricity output (% of total electricity output) |
| | | Renewable energy consumption (% of total final energy consumption) |
| | Environment/climate risk & resilience (6) | Cooling Degree Days (projected change in number of degree Celsius) |
| | | Droughts, floods, extreme temperatures (% of population, average 1990-2009) |
| | | Heat Index 35 (projected change in days) |
| | | Maximum 5-day Rainfall, 25-year Return Level (projected change in mm) |
| | | Mean Drought Index (projected change, unitless) |
| | | Population density (people per sq. km of land area) |
| | Food security (3) | Agricultural land (% of land area) |
| | | Agriculture, forestry, and fishing, value added (% of GDP) |
| | | Food production index (2014-2016 = 100) |

**Table 1A.** Continued

| Category | Theme | Series |
|---|---|---|
| Social Pillar (18) | Education & skills (3) | Government expenditure on education, total (% of government expenditure) |
| | | Literacy rate, adult total (% of people ages 15 and above) |
| | | School enrollment, primary (% gross) |
| | Employment (3) | Children in employment, total (% of children ages 7-14) |
| | | Labor force participation rate, total (% of total population ages 15-64) (modeled ILO estimate) |
| | | Unemployment, total (% of total labor force) (modeled ILO estimate) |
| | Demography (3) | Fertility rate, total (births per woman) |
| | | Life expectancy at birth, total (years) |
| | | Population ages 65 and above (% of total population) |
| | Health & nutrition (5) | Cause of death, by communicable diseases and maternal, prenatal and nutrition conditions (% of total) |
| | | Mortality rate, under-5 (per 1,000 live births) |
| | | Prevalence of overweight (% of adults) |
| | | Prevalence of undernourishment (% of population) |
| | | Hospital beds (per 1,000 people) |
| | Access to services (4) | Access to clean fuels and technologies for cooking (% of population) |
| | | Access to electricity (% of population) |
| | | People using safely managed drinking water services (% of population) |
| | | People using safely managed sanitation services (% of population) |
| Governance Pillar (18) | Human rights (2) | Strength of legal rights index (0 = weak to 12 = strong) |
| | | Voice and Accountability: Estimate |
| | Government effectiveness (2) | Government Effectiveness: Estimate |
| | | Regulatory Quality: Estimate |
| | Stability & rule of law (4) | Control of Corruption: Estimate |
| | | Net migration |
| | | Political Stability and Absence of Violence/Terrorism: Estimate |
| | | Rule of Law: Estimate |
| | Economic environment (3) | Ease of doing business rank (1 = most business-friendly regulations) |
| | | GDP growth (annual %) |
| | | Individuals using the Internet (% of population) |

**Table 1A.** Continued

| Category | Theme | Series |
|---|---|---|
| Governance Pillar (18) | Gender (4) | Proportion of seats held by women in national parliaments (%) |
| | | Ratio of female to male labor force participation rate (%) (modeled ILO estimate) |
| | | School enrollment, primary and secondary (gross), gender parity index (GPI) |
| | | Unmet need for contraception (% of married women ages 15-49) |
| | Innovation (3) | Patent applications, residents |
| | | Research and development expenditure (% of GDP) |
| | | Scientific and technical journal articles |