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EXPORT DIVERSIFICATION AND THE GREEN ECONOMY: THE KEY ROLE OF ECONOMIC RISK

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Abstract. As countries propose to develop their green economy strategies to achieve sustainable development goals, many researchers and practitioners have analyzed the various factors affecting this special economy and how export diversification impacts the environment. However, there is limited knowledge about the link between export diversification and the green economy. Thus, this research study explored the impact of such diversification on the green economy by considering the role of economic risk. A new dynamic panel threshold approach was applied to the global panel data of 112 countries from 1995 to 2014. The results support the U-shaped correlation between export diversification and the green economy with an increase in economic risk. Export diversification tends to weaken the green economy when economic risk is at lower levels, but it improves the economy after reaching a certain level of economic risk. We also found that the green economy has a persistent effect over time. Under all economic risk levels, the previous level of green economy development promotes current green economy development. These findings thus provide policymakers with crucial implications.

Keywords: export diversification, green economy, economic risk, dynamic threshold panel.

JEL Classification: C33, F18, O55, Q56.

Introduction

With the ecological crisis typified by global warming being more prominent over the past few decades, establishing a sustainable economy has become an issue of greater urgency than ever before (Hussain & Lee, 2022; Zou et al., 2022; Wen et al., 2023; Liu & Mishra, 2022; Lee et al., 2022c, 2023b). To achieve the United Nations' sustainable development goals, numerous nations have initiated the process of developing their green economies. Pearce et al. (1989) first put forward the concept of a green economy, stating that it is an economic form centered

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on the material basis of a green technology system and a value basis for improvement in environmental-related issues. The United Nations Environment Programme [UNEP] (2011) also defined a green economy as one that conserves resources and protects the environment. Both "green" and "economy" must be considered to realize this kind of development model. Since a green economy involves the effective use of low-carbon resources and can achieve a sustainable economic structure, its influencing factors have gained broad interest among policymakers and scholars.

The literature has explored the issue of green economy from many aspects. One line of research strand puts their efforts into constructing a suitable indicator for evaluating the development of a green economy (OECD, 2011; The United Nations Department of Economic and Social Affairs [UNDESA], 2012; He et al., 2019; Mealy & Teytelboym, 2022; Imanov, 2021; Lee & Lee, 2022; Lee et al., 2023a). For example, Can et al. (2021a, 2021b) developed a new green openness index by measuring trade in green technology products. They found that the green openness index can decrease the ecological footprint and stimulate environmental sustainability. Another branch of research investigates the key factors affecting the green economy. Scholars have investigated many factors that influence a green economy, including economic openness, fiscal spending, manufacturing industry, renewable energy, and technology innovation (Lorek & Spangenberg, 2014; He et al., 2019; Song et al., 2019; Yuan et al., 2020). To date, these works have aimed to solve the problem of how the green economy can be further developed.

With the progress of globalization, some academics have recognized the effect of export diversification (ED) on both the economy and the environment (Imbs & Wacziarg, 2003; Can & Gozgor, 2018; Fang et al., 2019; Wang et al., 2020; Lee & Ho, 2022; Lee et al., 2022a). ED is defined as a change in an economy's export and production structure (International Monetary Fund [IMF], 2014a, 2014b) that may occur through products/trading partners and is classified into extensive/intensive margins of diversification. The former denotes an increase in products/trading partners, whereas the latter refers to the share of more active products/trading partners. In other words, these two indicators measure the diversification of exports across sectors and within a sector, respectively (Can & Gozgor, 2018). Such differentiation allows policymakers to formulate more informed green economy decisions – to focus more on diversification across sectors or more on diversification within a sector. Therefore, ED measures a country's export product structure and its level of openness. Imbs and Wacziarg (2003) found an inverted U-shaped association between ED and economic growth as income level rises. Can and Gozgor (2018) found that the upgrade of export baskets is facilitated by the diversification of exports for countries with high-value product exports. Based on the *Environmental Kuznets Curve* (*EKC*) theory, Shahzad et al. (2020) studied the heterogeneous and non-linear influence of ED on carbon emissions.

Although the previously mentioned views have shown that ED exudes an impact on the economy and the environment, they also hint at the importance of economic risk to the nexus. If a country's economic risk is low, then based on the risk aversion theory, it will be easier to implement ED policies (de Piñeres & Ferrantino, 1997). Moreover, economic risks are a critical influencing factor for a country's economic growth and environment (Lee & Lee, 2018; Lee et al., 2020a; Guo et al., 2022). The establishment of a green economy necessitates a thorough examination of both the broader economy and the environment. Given that it is generally agreed that ED has a non-linear influence on a country's economy and environment, the role of economic risk cannot be overlooked. Therefore, exploring the influence of various degrees of economic risk on the link between ED and the green economy has great practical significance for policymakers.

This research thus assesses the non-linear influence of ED on a green economy by utilizing the dynamic panel threshold (DPT) model introduced by Seo and Shin (2016) and Seo et al. (2019). One salient feature of this technique is the use of GMM estimates to cope with the possibility of endogeneity. Another advantage is the allowance of endogenous threshold variables, which makes them different from a traditional threshold model. Moreover, the introduction of the lagged dependent variable allowed us to reveal the persistent effect of a green economy.

The current research makes several potential contributions to earlier works. First, we enrich the literature by examining the connection between ED and the green economy for 112 countries from 1995 to 2014. Second, we implement the recently developed DPT technique to further consider the threshold effect of economic risk in the above linkage, with the consideration of the endogenous problem in the estimation procedure. Fourth, we employ new green economy complexity indicators and green economy development potential to more comprehensively assess green economy development.

Using economic risk as a threshold variable, our empirical results conclude that ED contributes to the green economy when the economic risk of a country is higher than the threshold value; otherwise, ED hinders the green economy. We find that the level of the previous green economy can help promote the development of the current green economy, regardless of the degree of economic risk. By using various indicators for green economy development and ED and by using different indicators of economic risk as threshold variables, these findings prove that the threshold effect is robust.

The other sections of this research are arranged as follows. Section 1 provides a summary of the most relevant issues in the literature regarding ED and the green economy. Section 2 illustrates the data and the empirical strategy used in this paper. Section 3 discusses the empirical findings. The last Section provides concluding remarks and policy recommendations.

1. Related literature

1.1. Green economy

Since Pearce et al. (1989) first put forward the notion of a green economy, extensive efforts have been made to explore its determinants. Some scholars and institutions have conducted research on how the green economy can be measured, but there is still no unified standard. The United Nations Department of Economic and Social Affairs (UNDESA, 2012), for example, recommends using certain stock market indices of green performance to measure green economy development. The Organization for Economic Cooperation and Development (OECD, 2011) assesses a green economy by constructing a composite index based on indicators describing the productivity of environmental resources, the natural asset base, the standard of living, policy responses, and economic opportunities.

He et al. (2019) stated that the green economy should include economic development, environmental performance, and the status of energy use; they established a green economy index for China based on those factors. Imanov (2021) believed that the green economy has different development models for different regions, which mainly depend on the economic characteristics of the region. The author proposed the National Green Economy Index based on 11 levels (environmental quality, GDP, green agriculture, green tourism, energy intensity) to measure Azerbaijan's green development level. Li et al. (2020) and Feng et al. (2022) used a data envelopment analysis model to evaluate green development. In summary, based on the theoretical perspective of green development policies, most scholars and institutions measure a country's green economic progress based on the economic, environmental, policy, and resource levels using the economy as a whole. Moreover, there is a significant gap between green economy theory and policy and actual implementation (Rodrik, 2014). Based on these indicators, it is not always possible to distinguish which ones are impacted by the production of real green products, nor is it possible to truly produce green products in a country and determine if a country can improve its competitiveness in developing its green economy by adjusting the industrial structure of green products. To address the shortcomings of the existing indicators, Mealy and Teytelboym (2022) followed strategies from economic complexity research to construct the *green complexity index* (*GCI*) and *green complexity potential* (*GCP*).

Although the measure of green economy development remains an open question, another strand of the literature has explored the factors that determine the green economy. Traditional economic theory posits that the determinants of economic growth are investment, human capital, and technological progress. Since the green economy requires environmental and resource issues to be considered in the process of growth, originating from the Ramsey model (Ramsey, 1928), some scholars have expanded their research framework by further incorporating natural resources and social capital (Dinda, 2014). In this regard, fiscal spending and industrial structure (Lin & Zhu, 2019; Yuan et al., 2020), energy technological innovation (Grover, 2013), and economic openness (Lee et al., 2023c; Song et al., 2019; Talberth & Bohara, 2006) have also been added to the model of factors influencing the development of the green economy.

Some researchers have also found that certain elements have non-linear and heterogeneous effects on the green economy. For example, He et al. (2019) used the threshold model to analyze the link between renewable energy investment and the green economy. Yuan et al. (2020) assessed the influence of manufacturing agglomeration on green economic efficiency in China and found a positive U-shaped relationship. Lee et al. (2020b) explored the heterogeneity and influence mechanism of China's green total factor productivity in various industries and regions by constructing a finite mixture model based on the Solow decomposition framework. Yan et al. (2020) applied the data envelopment analysis technique to evaluate China's green productivity and concluded that income levels shape the effect of new energy technology innovation on the country's green productivity growth.

As mentioned above, some scholars believe that economic openness is a vital factor affecting green economy development. For example, Talberth and Bohara (2006) validated the influence of such openness and found that it enhances green economic development. Song et al. (2019) found that the influence of openness varies in various regions of China. However, most scholars have used the proportion of trade in GDP to proxy a country's openness. According to Adam Smith's productivity theory and new growth theory, economic openness may result in export specialization or diversification. In the current study, we aimed to further understand the influence of ED on the development of a green economy.

1.2. Export diversification and economic development

The importance of production specialization and trade is emphasized in Adam Smith's productivity theory. However, structuralist theories have questioned this specialized theoretical proposition because in the 1950s and 1960s, the terms of trade in developing countries that exported long-term commodities deteriorated. This shows that it is necessary to transform the export mix from primary products to diversified manufactured products to maintain growth. The new growth theory further emphasizes the nature of exports by increasing product variety and improving product quality (Aghion & Howitt, 1997). Feenstra (2010) finds that in countries where exports constitute a greater share of GDP, the diversification of export varieties creates conditions for higher GDP growth.

The endogenous growth theory provides a framework for the growth effect of ED via innovation incentives, technology diffusion, and improved knowledge transfer efficiency (Young, 1991). According to this framework, some scholars have explored non-linearity and heterogeneity to determine the influence of ED on growth. Imbs and Wacziarg (2003) found that ED and economic development have an inverted U-shaped linkage with income growth. Feenstra and Kee (2008) developed a model that uses a GDP function to link long-term export varieties between countries and total factor productivity. Gozgor and Can (2016a) found that ED exerts a positive influence on the growth of low- and middle-income countries. Mania and Rieber (2019) investigated the nexus between ED and sustainable economic growth and found that the relationship between the two is heterogeneous. The difference in the region of a country will lead to a change in the relationship.

1.3. Export diversification and environment

Based on the analysis of economic growth theory, some scholars have used EKC theory to explore the influence of ED on environmental quality. Concerning the impact of ED on environmental quality, some scholars have used carbon emissions to measure environmental quality (Fang et al., 2009; Wang et al., 2020). Gozgor and Can (2016b) studied the influence of ED on the environmental quality of Turkey using carbon emissions to measure environmental quality and reported that ED deteriorates environmental quality.

Numerous studies have examined heterogeneity and non-linearity from the impact of ED on the environment. Shahzad et al. (2020) studied the influence of ED on carbon emissions; in both developing and developed countries, they found that ED increases carbon emissions. Focusing on G7 countries, Wang et al. (2020) discussed the non-linear and heterogeneous influence of ED on the control of carbon emissions. Mania (2019) used system GMM (SYS-GMM) to explore the association between ED and carbon emissions based on EKC theory and found that ED has a positive impact on carbon emissions. Can et al. (2020) employed the autoregressive distributed lag model to find that, over the long term, ED spurs an increase in carbon emissions.

From the studies mentioned above, we can see that many factors introduced into the research affect green economic growth and that the influence of ED on growth and the environment is nonlinear. However, the association between ED and the green economy has not yet been investigated. The present research utilizes a DPT technique to explore the influence of ED on the green economy and introduces economic risk as a threshold variable. Our empirical findings thus provide more insight into the nonlinear influence of ED on the green economy under different degrees of economic risk.

1.4. Role of economic and financial risk

Grossman and Krueger's (1995) nonlinear growth-environment nexus hypothesis has been widely regarded as the theoretical foundation for research on green economic growth. The main view behind this proposition is the existence of a threshold effect between economic growth and environmental degradation. With the increasingly complex global economy and the continuous improvement of evaluation index systems of the national environment, this threshold effect does not solely depend on a country's GDP growth, but also on its economic/financial risk. Following this vein, the literature has shown that the national environment exerts a major influence on a country's economic growth and environment (Lee & Lee, 2018; Lee et al., 2020a; Guo et al., 2022). For example, Guo et al. (2022) found that the nexus between inequality and carbon emissions lies in country risk. By adopting economic risk as the threshold variable, Lee et al. (2022b) also indicated that the influence of communication technology on energy security is inverted U-shaped. Thus, we postulate that the influence of ED on the green economy varies with economic/financial risk. On the one hand, the implementation of ED policies is easier for countries with low economic risk (de Piñeres & Ferrantino, 1997). On the other hand, ED can reduce the risk level of countries with higher economic risks to ensure economic growth, and the advancement of production technology brought about by ED is conducive to environmental protection.

2. Data and methodology

2.1. Basic framework

To develop a proper framework for assessing the influence of ED on the green economy, we should understand the influencing factors of the green economy. The literature has identified that the green economy is a function of investment, human capital, industrialization level, non-fossil fuel, and ED. Following Yuan et al. (2020) and considering the time duration effect of the green economy, we first propose the following baseline model:

$$GE_{it} = \beta_0 + \beta_1 GE_{it-1} + \beta_2 ED_{it} + \beta_3 FDI_{it} + \beta_4 HC_{it} + \beta_5 Industry_{it} + \beta_6 Nonfossil_{it} + \varepsilon_{it}. \quad (1)$$

Among them, $i = 1, \ldots, N$ and $t = 1, \ldots, T$ denote the country and the time period, respectively; GE_{it} is an indicator of the green economy; GE_{it-1} is the lagged value of the green economy; ED_{it} measures for export diversification; FDI_{it} represents foreign direct investment net inflows; HC_{it} is the value of the human capital index; $Industry_{it}$ denotes the percentage of the secondary industry in GDP; $Nonfossil_{it}$ is the percentage of non-fossil fuels in total fuel consumption; and ε_{it} is the error term.

2.2. Variables and measures

2.2.1. Measures of the green economy (GE)

Considering that it is difficult to perform a single-index evaluation to reveal the overall picture of a green economy, we followed Mealy and Teytelboym (2022) in constructing GCI and GCP using methods from the economic complexity literature. As noted by Can and Gozgor (2017), economic complexity represents a knowledge- and skill-based production structure of a country with an efficient production structure. The former index can be used to understand the extent to which countries export various technologically advanced green products in a competitive manner, and it reflects the competitiveness of countries in exporting green and technologically advanced products. High-GCI countries tend to have a greater awareness of environmental protection, lower CO_2 emissions, and tightened environmental policies. They are also more competitive at exporting various technologically advanced green products, and vice versa. The latter index aggregates the information contained in the gaps of each country into a single comparable amount. It measures the average degree of association between each country and its green composite products, which are not yet competitive, so that we can forecast a country's green product exports and green development. The higher the GCP, the better the country's prospects for diversification of green and technologically advanced products; thus, the share of green exports and the number of competitive green products will increase, and vice versa.

The specific calculation methods for GCI and GCP are as follows. First, we calculate the GCI based on the measuring method of the Product Complexity Index (PCI), which is drawn from the COMTRADE database. Following Hausmann et al. (2014), we then set a binary country–product matrix M_{cp} indexed by country c and product p. For a given country c showing a *revealed comparative advantage* ($RCA > 1$) calculated by the following equation on product p, M_{cp} is equal to 1 and 0 otherwise.

$$RCA_{\mathrm{cp}} = \frac{x_{cp} / \sum_p x_{cp}}{\sum_c x_{cp} / \sum_c \sum_p x_{cp}}, \tag{2}$$

where x_{cp} is the export of country c to product p. Using the M matrix, we could assess how many countries in a particular product have RCA. We used the calculation method of PCI to calculate the GCI as follows:

$$GCI_c = \sum_g \rho_g^c \widetilde{PCI}, \tag{3}$$

where ρ_g^c denotes a binary variable that equals 1 for the existence of a *revealed comparative advantage* in country c on green product g and 0 otherwise. It standardizes the complexity index of the green product g and takes a value between 0 and 1. Finally, the GCI was standardized by its mean and standard deviation.

To understand the potential of green products in countries that are not currently competitive, we measured GCP. This evaluates how much potential there is to further diversify the production of green and technologically complex products in the future. In this regard, country c's GPC can be expressed as follows:

$$GCP_c = \frac{1}{\sum_g (1-\rho_g^c)} \sum_g (1-\rho_g^c)\omega_g^c \widetilde{PCI}_g, \tag{4}$$

where $1-\rho_g^c$ refers to no RCA for green product g in country c; ω_g^c represents the distance from green product g to country c; and $\widetilde{PCI}$ represents the PCI of green production g. The GCP is standardized by its mean and standard deviation.

Both GCI and GCP can be used to assess the development of a country's green economy. The higher the value of these measures, the greater the development of a green economy. When comparing these two measures, research shows a significant difference between GCI and GCP (Fraccascia et al., 2018; Mealy & Teytelboym 2022). Countries with higher GCP usually find it easier to achieve a high GCI.

2.2.2. Measures of export diversification (ED)

We take a measurement mainly based on the definition and the Theil index method used by Cadot et al. (2011) to construct the overall export diversification (*EXD*), export extensive margin (*EXE*), and export intensive margin (*EXI*) indices. First, we introduced dummy variables specifying products as traditional/new/non-traded. "Traditional" refers to products that were exported in the initial sample period, whereas "non-traded" refers to no exports of this product throughout the sampling period. In this regard, for the products of each country, the dummy values assigned to traditional and non-traded products remained the same in all years. Furthermore, products labeled as "new" must be non-traded products for at least the first two years and then exported for the next two years. Therefore, the dummies for these new products will change over time.

According to Cadot's et al. (2011) definition, the *EXD* index is the sum of the *EXE* and the *EXI*. The *EXE* index T_B for each country can be estimated as follows:

$$T_B = \sum\nolimits_K \left(N_K / N\right)\left(\mu_K / \mu\right) ln\left(\mu_K / \mu\right), \tag{5}$$

where K denotes the individual group that was defined earlier; N_K represents the total products exported by each group, and μ_K / μ is the relative average of each group's exports.

The *EXI* index T_W for each country can be estimated as follows:

$$T_W = \sum\nolimits_K \left(N_K / N\right)\left(\mu_K / \mu\right)\left\{\left(1 / N_K\right)\sum\nolimits_{i \in IK}\left(X_i / \mu_K\right) ln\left(X_i / \mu_K\right)\right\}. \tag{6}$$

For a given country, X refers to export value. Given that the *EXD* index and the *EXE* are calculated using the Thiel index method, the higher the value, the lower the level of diversification. *EXI* is defined as the share of more active products/trading partners. When a country's export income is generated by only a few sectors or trading partners, it is less diverse. Therefore, a larger *EXI* indicates a greater degree of ED (IMF, 2014a, 2014b).

2.2.3. Threshold variables

(1) Economic risk (*ER*) was from the International Country Risk Guide (ICRG). It is usually used to assess a country's economic risk (e.g., Chiu & Lee, 2019; Wu et al., 2020; Guo et al., 2022). A high value indicates a lower economic risk.

(2) Financial risk (*FR*) was proxied by ICRG. It is usually used to assess the financial risk of a country (e.g., Lee & Lee, 2019; Lee et al., 2020a). A high value means lower financial risk.

2.2.4. Control variables

(1) Foreign direct investment (*FDI*) was calculated by the FDI net inflow as a percentage of GDP. The improvement of resource allocation efficiency and technological progress brought about by capital is beneficial to economic conditions and environmental protection (Lin & Zhu, 2019; Yuan et al., 2020).
(2) Human capital (*HC*) was proxied by years of schooling and returns to education, which were obtained from the World Development Indicator (WDI). According to the new growth theory, HC promotes economic growth and affects environmental quality by boosting technological progress (Balaguer & Cantavella, 2018).
(3) Industrialization level (*Industry*) was measured as the proportion of the added value of the secondary industry in the GDP. Industry is regarded as the main factor in environmental pollution, and rapid industrialization leads to increased environmental pollution (Wen & Lee, 2020; Zhou et al., 2022).
(4) Non-fossil (*Nonfossil*) was assessed by non-fossil fuel consumption as a percentage of total fuel consumption. A higher proportion of non-fossil fuels in the energy consumption structure is conducive to environmental protection (Li et al., 2019).

Tables A1 and A2 (Appendix) contain extensive explanations and references for all variables and their corresponding descriptive statistics. Table 1 presents the correlation matrix.

Table 1. Correlation matrix among the variables

	EXE	EXI	EXD	FDI	HC	Industry	Nonfossil
EXE	1						
EXI	−0.0270	1					
	0.209						
EXD	−0.0150	0.265***	1				
	0.485	0.000					
FDI	−0.045**	0.036*	0.083***	1			
	0.034	0.091	0.000				
HC	−0.303***	−0.234***	−0.141***	0.077***	1		
	0.000	0.000	0.000	0.001			
Industry	−0.162***	−0.0180	−0.0340	0.0300	0.128***	1	
	0.000	0.386	0.106	0.156	0.000		
Nonfossil	−0.053**	0.0270	0.099***	−0.097***	−0.385***	−0.061***	1
	0.017	0.218	0.000	0.000	0.000	0.006	

Note: $^{*}p < 0.1$, $^{**}p < 0.05$, and $^{***}p < 0.01$.

2.3. Empirical methodology

In this study, we applied the DPT model to assess the nexus between ED and green economy development and to determine how economic risk will affect this relationship. The general setting of this method can be expressed in the following equation:

$$y_{it} = x'_{it}\beta + \left(1, x'_{it}\right)\delta 1\left\{q_{it} > \gamma\right\} + \mu_i + \varepsilon_{it}, \tag{7}$$

where y_{it} is the dependent variable in country i at time t; x_{it} stands for the set of regressors; $1\{.\}$ is an indicator function; q_{it} is the threshold variable used to distinguish different regions. Thus, our empirical model can be specified as follows:

$$GCI_{it} = \beta_0 + \beta_1 GCI_{it-1} + ED'_{it}\beta + \left(1, ED'_{it}\right)\delta 1\left\{ER_{it} > \gamma\right\} + Control'_{it}\omega + \left(1, Control'_{it}\right)\delta 1\left\{ER_{it} > \gamma\right\} + \mu_i + \varepsilon_{it}, \tag{8}$$

where GCI_{it} denotes the green complexity index; ED_{it} represents export diversification (proxied by *EXD*, *EXE*, and *EXI* indices); and $Control'_{it}$ refers to a group of control variables, including *HC*, *Industry*, *FDI*, and *Nonfossil*. Moreover, ER_{it} is a threshold variable.

To study the non-linear impact of ED on the development potential of the green economy, we introduced a different dependent variable (GCP) into the model:

$$\mathrm{GCP}_{it} = \beta_0 + \beta_1 \mathrm{GCP}_{it-1} + ED'_{it}\beta + \left(1, ED'_{it}\right)\delta 1\left\{ER_{it} > \gamma\right\} + Control'_{it}\omega + \left(1, Control'_{it}\right)\delta 1\left\{ER_{it} > \gamma\right\} + \mu_i + \varepsilon_{it}, \tag{9}$$

where GCP_{it} denotes the green complexity potential of country i in year t. As is widely known, countries with high economic risk also have high financial risks. Thus, we chose financial risk (FR_{it}) as another threshold variable as follows:

$$GCI_{it} = \beta_0 + \beta_1 GCI_{it-1} + ED'_{it}\beta + \left(1, ED'_{it}\right)\delta 1\left\{FR_{it} > \gamma\right\} + Control'_{it}\omega + \left(1, Control'_{it}\right)\delta 1\left\{FR_{it} > \gamma\right\} + \mu_i + \varepsilon_{it}. \tag{10}$$

Finally, we lagged all the independent variables by one period to test the robustness of our empirical results. The model is set as follows:

$$GCI_{it} = \beta_0 + \beta_1 GCI_{it-1} + ED'_{it-1}\beta + \left(1, ED'_{it-1}\right)\delta 1\left\{ER_{it} > \gamma\right\} + Control'_{it-1}\omega + \left(1, Control'_{it-1}\right)\delta 1\left\{ER_{it} > \gamma\right\} + \mu_i + \varepsilon_{it}. \tag{11}$$

3. Empirical results

3.1. Basic discovery

Before estimating the influence of ED on the green economy, it is meaningful to assess the stationarity properties of the sample data. Table 2 presents the corresponding results of Levin et al. (2002, LLC) and Fisher-ADF unit root tests for each variable. The statistical results consistently reveal that all the variables are stable and can be utilized for the estimation that comes next. We also present the results of the variance inflated factor (VIF) for each variable. Evidence shows that the highest VIF is 1.25 and the mean VIF is 1.10, which is far below the threshold of 10, suggesting that multicollinearity is an unlikely problem in our empirical models. As seen in Table 3, we took an additional step to test the problems of cross-sectional dependence using the Pesaran (2004) and Friedman (1937) tests. The testing results cannot reject the null hypothesis of contemporaneous correlation, suggesting no cross-sectional dependency.

Next, we applied the ordinary least squares (OLS) and random effect (RE) techniques, as illustrated in Eq. (1), to detect the overall impact of *EXD* on green economy development measured by GCI. To analyze the persistence of the green economy and avoid any possible endogeneity in the model, we also used SYS-GMM. Table 4 presents the corresponding results and reveals that *EXD* exerts a significant influence on green economy development, but the direction, intensity, and significance differ due to distinct estimating approaches. For the persistence of the coefficient measures, we found that the green economy in the previous year enhances the current year's green economy.

Table 2. Panel unit root and multicollinearity tests

Variable	LLC		Fisher-ADF	VIF
	Constant	Constant with trend		
GCI	−4.043*** (0.000)	−9.293*** (0.000)	612.958*** (0.000)	–
GCP	−7.127*** (0.000)	−7.601*** (0.000)	625.986*** (0.000)	–
EXD	−7.456*** (0.000)	−10.853*** (0.000)	638.846*** (0.000)	1.04
EXE	−7.852*** (0.000)	−8.552*** (0.000)	655.629*** (0.000)	1.09
EXI	−4.737*** (0.000)	−8.697*** (0.000)	636.378*** (0.000)	1.07
FDI	−11.211*** (0.000)	−12.620*** (0.000)	710.351*** (0.000)	1.03
HC	−1.421*** (0.078)	−6.648*** (0.000)	408.615*** (0.000)	1.25
Industry	−48.844*** (0.000)	−0.010*** (0.000)	723.728*** (0.000)	1.01
Nonfossil	–	–	391.144*** (0.000)	1.18
Mean VIF				1.10

Notes: The numbers indicated in parentheses are p-values. *$p < 0.1$, ** $p < 0.05$, and *** $p < 0.01$.

Table 3. Cross-sectional dependence test

	Pesaran (2004) test	Friedman (1937) test
C-D test	0.317	16.736
P-value	0.751	1.000

Notes: The null hypothesis of Pesaran and Friedman tests is that there is no contemporaneous autocorrelation between groups. *$p < 0.1$, ** $p < 0.05$, and *** $p < 0.01$.

In summary, we did not observe any clear pattern from linear specifications for the impact of ED on green economy development. Considering that economic activities and the environment in a country are affected by their economic risk, and the traditional linear regression method shows some inability to handle structure breaks, we reexamined how economic risk exerts its non-linear influence by utilizing the DPT model of Seo and Shin (2016) to investigate the changes in the impact of ED on green economy development at different economic risk intervals.

Table 4. Estimation results of the basic model

Variable	Dependent variable: GCI		
	OLS	RE	SYS-GMM
EXD	−0.106***	0.032***	−0.007*
	(0.000)	(4.23)	(0.072)
FDI		−0.002*	−0.0001
		(−1.88)	(0.779)
HC		1.244***	−0.071**
		(9.35)	(0.021)
Industry		−0.005	0.003
		(−1.10)	(0.620)
Nonfossil		−0.002*	−0.0004
		(−1.90)	(0.173)
GCI_{t-1}			0.953***
			(0.000)
cons	0.402***	−0.156***	−0.051
	(0.000)	(0.287)	(0.419)
R^2/ Wald Test	0.0211	0.024	26206.35***
AR(2) (p-value)			0.147
Hansen Test (p-value)			0.114
Observations	2240	1959	1860
Number of countries	112	99	99

Notes: The numbers indicated in parentheses are standard errors. *$p < 0.1$, ** $p < 0.05$, and *** $p < 0.01$.

3.2. Dynamic panel threshold model

To evaluate whether there is a non-linear linkage between ED and the green economy, we used the bootstrapping algorithm technique of Seo and Shin (2016) to test the threshold effect and the linearity property. Table 5 reports the outcomes, together with the threshold value and confidence intervals for the cases in which ER and FR are deemed to be the threshold variable. These results strongly reject the null hypothesis of no threshold effects and linearity at the 1% level regardless of whether the threshold variable is used. We thus conclude that the linear technique is not appropriate for modeling the nexus between ED and the green economy, which confirms the findings of Shahzad et al. (2020), Wang et al. (2020), and Mania (2019) on the nexus between ED and the environment.

Table 5. Testing results for linearity and the threshold effect

Dependent variable	Core independent variable	Threshold variable	Threshold value	Standard error	z	P>|z|	95% conf. interval	Bootstrap p-value	Bootstrap
GCI	EXD	Economic risk	32.500***	0.780	41.69	0.000	[30.972, 34.028]	0.000	1000
		Financial risk	35.000***	0.669	52.32	0.000	[33.689, 36.311]	0.000	1000
	EXE	Economic risk	33.507***	0.623	53.78	0.000	[32.286, 34.728]	0.000	1000
		Financial risk	39.500***	0.969	40.77	0.000	[37.601, 41.399]	0.000	1000
	EXI	Economic risk	37.510***	0.615	60.94	0.000	[36.304, 38.716]	0.000	1000
		Financial risk	36.500***	0.959	38.06	0.000	[34.620, 38.380]	0.000	1000
	EXD_{t-1}	Economic risk	38.517***	0.866	44.49	0.000	[36.820, 40.213]	0.000	1000
		Financial risk	40.500***	0.675	60.03	0.000	[39.177, 41.822]	0.000	1000
GCP	EXD	Economic risk	38.517***	1.034	37.25	0.000	[36.490, 40.543]	0.000	1000
	EXE	Economic risk	38.002***	0.858	44.31	0.000	[36.321, 39.683]	0.000	1000
	EXI	Economic risk	38.517***	1.193	32.29	0.000	[36.179, 40.855]	0.000	1000

Notes: $^*p < 0.1$, ** $p < 0.05$, and *** $p < 0.01$.

Once the threshold effects are confirmed, we can conduct the DPT analysis further, as illustrated in Eq. (8). Table 6 presents the results when using economic risk as the threshold variable. The estimates in Columns (1)–(6) reflect the importance of three ED assessment areas, including *EXD*, *EXE*, and *EXI*, in affecting green development. For the overall *EXD*, the results in Columns (1) and (2) reveal that the coefficients of *EXD* are positive (negative) and significant when the economic risk is lower (higher) than the threshold value. Given that a high *EXD* index reflects a low level of diversification, these findings signify that *EXD* inhibits (stimulates) the development of the green economy when economic risk is low (high). We thus conclude that the influence of ED is heterogeneous, indicating that they do not affect green economy development in a uniform way (Shahzad et al., 2020; Wang et al., 2020; Mania, 2019). These findings may partly explain the mixed evidence on the linkage between ED, economic growth, and the environment (Gozgor & Can, 2016a, 2016b; Can & Gozgor, 2017; Mania & Rieber, 2019; Can et al., 2021a).

Regarding the *EXE* index, the results in Columns (3)–(4) reveal that the coefficients of *EXE* are significantly positive (negative) when the economic risk is below (above) the threshold value. Given that a high *EXE* index represents a low level of *EXE*, the results indicate that the *EXE* inhibits (stimulates) green economy development when economic risk is low (high).

Table 6. DPT estimations for GCI (threshold = ER)

Variable	Dependent variable: GCI					
Threshold variable	Economic risk		Economic risk		Economic risk	
	Higher	Lower	Higher	Lower	Higher	Lower
GCI_{t-1}	0.040	0.085***	0.069	0.120***	0.538***	0.045***
	(0.036)	(0.012)	(0.043)	(0.011)	(0.052)	(0.009)
EXD	−0.032*	0.075***				
	(0.017)	(0.014)				
EXE			−0.609***	0.373***		
			(0.074)	(0.049)		
EXI					0.044***	−0.142***
					(0.013)	(0.010)
FDI	−0.002***	0.003***	0.001*	−0.002***	−0.002***	0.002***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
HC	0.343***	−0.377***	−0.013	−0.235***	0.164***	−0.094
	(0.116)	(0.101)	(0.126)	(0.070)	(0.047)	(0.060)
Industry	−0.054**	0.078***	−0.020**	0.043***	0.010***	0.007
	(0.024)	(0.020)	(0.010)	(0.011)	(0.003)	(0.008)
Nonfossil	−0.003***	−0.002**	−0.003***	0.003***	−0.000	−0.001*
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Number of countries	82		82		82	
Observations	1640		1640		1640	

Notes: The numbers indicated in parentheses are standard errors. *$p < 0.1$, ** $p < 0.05$, and *** $p < 0.01$.

With respect to the *EXI* index, Columns (5)–(6) reveal that the coefficients of *EXI* are significantly negative (positive) when the economic risk is lower (greater) than the threshold value. Given that a high *EXI* index represents a higher ED, the results also demonstrate that the *EXI* index inhibits (stimulates) green economy development when economic risk is low (high).

The estimation results shown in Table 6 also indicate that, no matter how well economic risk performs, green economy development in the previous period will last from one year to the next. In other words, the green economy has a positive time duration effect, which is significant at the 1% level. These results confirm the findings of Li and Lin (2017), Cheng et al. (2020), and Yuan et al. (2020), who noted that green economic development has a positive time lag effect. Such an effect will accumulate over time.

In summary, regardless of whether the overall *EXD* index or its two sub-indices are used, our empirical results suggest that ED and green economy have a non-linear U-shaped relationship that is remarkably influenced by economic risk. This finding may be explained in part by the correlation between high economic risk and low economic development levels.

These countries tend to intensify efforts to expand their export commodities and trading partners to obtain capital and ensure technological progress to achieve economic development, as posited in the international trade literature (Can et al., 2021a). Therefore, the introduction of additional capital and advanced technology promotes local economic growth and improves the environment, thereby being conducive to green economy development. As Papageorgiou and Spatafora (2012) noted, underdeveloped areas with high risk generally develop their economies and improve the environment by accepting capital and technology from developed areas with low risk. Therefore, countries with high risk realize economic growth and environmental protection through ED. For low-risk countries that have realized specialization in production and trade, ED is not conducive to environmental protection and economic growth (Mania & Rieber, 2019).

The analysis presented above documents the non-linear impact of ED on the green economy and the time-duration effect of the green economy. These analyses use GCI as a dependent variable to capture the competitiveness of countries in exporting green and technologically advanced products. However, it is also interesting to understand the extent of the impact of ED on the potential of a country to develop a green economy in the future. To this end, we replaced GCP as an alternative dependent variable in our DPT model. Table 7 presents the parameter estimates, as demonstrated in Eq. (9), when using economic risk as the threshold variable.

The results are basically consistent with the estimated results of Eq. (8). The empirical results show that ED can inhibit the green economy's complexity potential in low-economic-risk countries, but it will increase the green economy's potential when economic risk is higher than a certain threshold. However, the time duration effect of GCP is different from that of GCI. The empirical findings indicate that the previous GCP will weaken the current GCP when economic risk is low and that the previous GCP will strengthen the current GCP when such risk reaches a certain level. It is worth mentioning that when facing with high economic risk, the influence coefficient of the previous GCP on the current GCP is significantly higher than when economic risk is low. This indicates that in areas with low economic risk, the potential for the green economy does not have a strong time continuity, whereas the potential for green economic development in areas with high economic risk has a high degree of time correlation.

3.3. Robustness check

In our previous empirical investigation, economic risk was considered the main risk that changes the relationship between ED and green economy development. To check whether the results vary with different threshold variables, we replaced economic risk with financial risk. Table 8 summarizes the corresponding estimates for the DPT model, as stated in Eq. (10). The results are essentially the same as those shown in Table 6. The results still reveal that the effect of ED on green economy development is considerably influenced by financial risk. An increase (decrease) in ED inhibits the growth of the green economy in countries with low (high) financial risk. In summary, the robustness test results mostly confirm our earlier conclusions.

Table 7. DPT estimations for GCP (threshold = ER)

Variable	Dependent variable: GCP					
Threshold variable	Economic risk		Economic risk		Economic risk	
	Higher	Lower	Higher	Lower	Higher	Lower
GCP_{t-1}	0.536***	–0.028***	0.559***	–0.016**	0.488***	–0.020*
	(0.052)	(0.009)	(0.040)	(0.008)	(0.042)	(0.011)
EXD	–0.030***	0.036***				
	(0.006)	(0.009)				
EXE			–0.110**	0.110***		
			(0.051)	(0.026)		
EXI					0.004	0.060***
					(0.010)	(0.009)
FDI	0.001***	–0.001**	0.001**	–0.001*	–0.000	0.001***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
HC	0.188***	–0.284***	0.057	–0.263***	0.191***	–0.240***
	(0.062)	(0.075)	(0.059)	(0.058)	(0.063)	(0.078)
Industry	0.004	0.017***	0.029***	–0.031***	0.021***	–0.009
	(0.004)	(0.004)	(0.007)	(0.010)	(0.003)	(0.006)
Nonfossil	–0.001***	–0.003***	–0.000	–0.004***	–0.001***	–0.002***
	(0.000)	(0.001)	(0.001)	(0.001)	(0.000)	(0.001)
Number of countries	82		82		82	
Observations	1640		1640		1640	

Notes: The numbers indicated in parentheses are standard errors. *$p < 0.1$, ** $p < 0.05$, and *** $p < 0.01$.

Table 8. DPT estimations for GCI (threshold = FR)

Variable	Dependent variable: GCI					
Threshold variable	Financial risk		Financial risk		Financial risk	
	Higher	Lower	Higher	Lower	Higher	Lower
GCI_{t-1}	0.325***	0.021**	–0.070**	–0.007	0.224***	–0.084***
	(0.046)	(0.010)	(0.033)	(0.007)	(0.031)	(0.010)
EXD	–0.099***	0.125***				
	(0.015)	(0.011)				
EXE			–0.306***	0.395***		
			(0.090)	(0.078)		
EXI					–0.041***	–0.017
					(0.015)	(0.013)
FDI	0.005***	–0.005***	–0.005***	0.005***	–0.005***	0.005***
	(0.001)	(0.001)	(0.000)	(0.000)	(0.001)	(0.001)
HC	0.496***	–0.085	–0.084	0.402***	0.050	0.165***
	(0.066)	(0.086)	(0.104)	(0.082)	(0.087)	(0.042)
Industry	0.066***	–0.042**	–0.001	0.017	0.010	0.005
	(0.018)	(0.017)	(0.002)	(0.012)	(0.015)	(0.020)

End of Table 8

Variable	Dependent variable: GCI					
Threshold variable	Financial risk		Financial risk		Financial risk	
	Higher	Lower	Higher	Lower	Higher	Lower
Nonfossil	0.004***	–0.002**	–0.004***	–0.002***	–0.006***	–0.004***
	(0.001)	(0.001)	(0.000)	(0.001)	(0.001)	(0.001)
Number of countries	82		82		82	
Observations	1640		1640		1640	

Notes: The numbers indicated in parentheses are standard errors. *$p < 0.1$, ** $p < 0.05$, and *** $p < 0.01$.

We also lagged all the independent variables by one period to account for the time lag effect. Table 9 lists the corresponding results in Eq. (11), based on the DPT estimation. By lagging all the independent variables into one period, we found that the level of the green economy development in the previous period has a positive time continuation effect regardless of the degree of economic risk, and the relationship between ED and green economy is a U-shape with the increase of economic risk. These results all suggest that our earlier findings are robust in this respect.

Table 9. DPT estimations for GCI (threshold = ER)

Variable	Dependent variable: GCI					
Threshold variable	Economic risk		Economic risk		Economic risk	
	Higher	Lower	Higher	Lower	Higher	Lower
GCI_{t-1}	0.348***	0.093***	0.361***	0.048***	0.323***	0.064***
	(0.052)	(0.009)	(0.036)	(0.012)	(0.020)	(0.007)
EXD_{t-1}	–0.045***	0.036***				
	(0.006)	(0.007)				
EXE_{t-1}			–0.241***	0.152***		
			(0.087)	(0.039)		
EXI_{t-1}					0.020***	0.017*
					(0.005)	(0.009)
FDI_{t-1}	–0.001***	0.002***	–0.000	0.001*	–0.000	0.001
	(0.000)	(0.001)	(0.000)	(0.001)	(0.000)	(0.001)
HC_{t-1}	0.175***	–0.341***	–0.139**	–0.147	0.039	–0.409***
	(0.064)	(0.076)	(0.067)	(0.106)	(0.100)	(0.054)
$Industry_{t-1}$	0.004	–0.014***	0.008***	–0.032***	–0.012***	–0.011**
	(0.004)	(0.004)	(0.001)	(0.006)	(0.003)	(0.004)
$Nonfossil_{t-1}$	–0.001*	0.002**	–0.000	–0.002**	–0.003***	–0.001**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Number of countries	87		87		87	
Observations	1740		1740		1740	

Notes: The numbers indicated in parentheses are standard errors. *$p < 0.1$, ** $p < 0.05$, and *** $p < 0.01$.

Conclusions and recommendations

A considerable number of researchers have investigated the non-linear and heterogeneous influences of ED on economic growth and the environment, but ED has not yet been explored as an influencing factor affecting green economy development. As a crucial policy issue affecting exports, economic condition, and the environment, how economic risk shapes the relationship between ED and the green economy has not been investigated. By adopting a global sample of 112 nations, we employed the DPT technique to explore the nonlinear nexus between ED and green economy, with the consideration of economic risk being the threshold variable.

Evidence reveals that the effect of ED on the green economy involves a threshold effect. We find that a high level of ED weakens (enhances) a green economy when a country's economic risk is low (high). The evidence also reveals the persistence effect of the green economy, implying that the previous green economy enhances the current green economy under all economic risk levels. For GCP, this effect is reversed, implying that previous GCP reduces the level of present GCP when economic risk is low, and GCP enhances the level of current GCP when economic risk is high.

Thus, our paper provides several insights into policy implications. First, we found that the effect of ED is heterogeneous under different risk conditions. Knowledge of this relationship can help prevent governments from conducting a "one-size-fits-all" policy. Policymakers should formulate green economy regulations and goals with consideration of their economic risk. For example, we found that ED reduces the green economy for countries with low economic risk. These countries should focus on resolving the issue of a green economic recession arising from the implementation of ED policies. In this regard, upgrading their export quality may be an appropriate strategy to foster green economic growth. For countries with high economic risk, policymakers should formulate ED guidelines so that exported goods can become specialized and the number of trading partners can be reduced to achieve green economic growth.

Finally, our research not only sheds light on how ED affects green economy development from a global perspective, but also suggests new avenues for further research. First, the growth pattern may be different at the stage of development being considered. Therefore, one future direction would be to differentiate between developed and developing countries. Second, the green economy is a complex term. Thus, analyzing various dimensions of green economy, such as the newly developed green openness index, may be another promising topic for future investigation.

Disclosure statement

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APPENDIX

Table A1. Summary of variables, definitions, and data sources

Variable	Definition	Source
	Dependent variables	
GCI	Green complexity index (A higher value denotes a more developed green economy)	Mealy and Teytelboym (2022) and COMTRADE export data
GCP	Green complexity potential (A higher value denotes a more developed green economy)	Mealy and Teytelboym (2022) and COMTRADE export data
	Core independent variables	
EXD	Overall export diversification index (A higher value denotes lower export diversification)	IMF
EXE	Export extensive margin index (A higher value denotes lower export diversification)	IMF
EXI	Export intensive margin index (A higher value denotes higher export diversification)	IMF
	Control variables	
HC	Natural logarithm of human capital based on years of schooling and returns to education	WDI
Industry	Natural logarithm of industry value added (% of GDP)	WDI
FDI	Foreign direct investment net inflows (% of GDP)	WDI
Nonfossil	Non-fossil energy consumption to total (%)	WDI
	Threshold variables	
ER	Economic risk rating (A higher value denotes lower economic risk)	ICRG
FR	Financial risk rating (A higher value denotes lower financial risk)	ICRG

Table A2. Summary of statistical properties

Variable	Mean	Mid	Max	Min	SD	Skewness	Kurtosis	Observations
Dependent variables								
GCI	0.0500	−0.399	4.197	−0.882	1.025	1.563	4.873	2240
GCP	0.0560	−0.173	3.445	−1.208	1.018	0.928	3.226	2240
Core independent variables								
EXD	3.334	3.292	6.417	0	1.411	−0.0490	2.564	2240
EXE	0.353	0.146	2.804	−0.0430	0.486	2.285	8.494	2240
EXI	3.026	2.934	5.960	0	1.152	0.221	2.967	2240
Control variables								
FDI	4.268	2.616	103.3	−15.84	6.886	6.049	60.39	2234
HC	0.889	0.950	1.318	0.0870	0.298	−0.715	2.723	2080
Industry	8.142	8.455	9.151	0	1.455	−4.416	24.50	2240
Nonfossil	30.16	21.81	96.77	0	26.18	0.847	2.676	2076
Threshold variables								
ER	35.40	35.50	50	9.500	6.122	−0.515	3.994	2210
FR	37.01	37.50	50	8	6.093	−0.761	4.404	2210