



Does natural resource dependence restrict green development? An investigation from the “Belt and road” countries

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ABSTRACT

Addressing natural resource dependence is integral to achieving the Sustainable Development Goals by promoting economic diversification, environmental sustainability, and climate resilience. This study explores the effect of natural resource dependence on green development by adopting the balanced panel dataset from the “Belt and Road” countries from 2005 to 2019. Notably, the novelty of our analysis lies in the empirical analysis using instrument-based techniques that consolidate the “green development curse hypothesis” in the Belt and Road countries. The mechanism analysis reveals that natural resource dependence curbs green development by weakening innovative capability, disturbing institutional quality, reducing population density, and crowding out human capital. Further, the dynamic panel threshold model handling endogeneity verifies the nonlinear relationship between natural resource dependence and green development. Interestingly, digital trade offers greater “resilience” than traditional trade, correcting the resource curse dilemma. Finally, heterogeneity analyses indicate that the green development curse hypothesis only exists in countries with high-level environmental regulations and resource-based countries.

List of abbreviations

BRI	Belt and Road Initiative
CE	CO ₂ emission
DE	Direct effect
EKC	Environmental Kuznets Curve
ERS	environmental regulation stringency
FD	Financial development
FDI	Foreign direct investment
GD	Green development
HC	Human capital
IE	Indirect effect
IND	Industrialization
IQ	Institutional quality
IV	Instrument variable
LA	Land area
NR	Natural resource
NRD	Natural resource dependence
NRDR	Natural resource dependence ranking
PD	Population density
PGDP	Per capita GDP
PTE	Proportion of total effect that is mediated

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RED	Resource economic dependence
REERI	Relative effective exchange rate index
RID	The ratio of the indirect to the direct effect
RTD	Resource employment dependence
RTI	The ratio of the total to the indirect effect
SYS-GMM	System generalized method of moment
TE	Total effect
TI	Technological innovation
URB	Urbanization

1. Introduction

China's Belt and Road Initiative (BRI) is a forward-looking strategy initiated by the Chinese central government to connect Asia with Africa and Europe via land and maritime networks. This plan aims to strengthen regional integration, increase trade cooperation, maintain sustainable economic growth, and achieve mutual benefits between participating partners. The name was coined in 2013 by Chinese

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President Xi, who drew inspiration from the concept of the Silk Road established during the Han Dynasty 2000 years ago – an ancient network of trade routes that connected China to the Mediterranean via Eurasia for centuries. Thus, the BRI has also been called ‘One Belt One Road’.

The BRI has related to an extensive project of investments in infrastructure construction, roads, airports, railways, unimpeded trade, telecommunications, and power plants. The project’s scale is committed to creating business opportunities in the region for a broad range of companies and service providers worldwide. Concurrent with pressing issues such as climate change, the BRI countries now concentrate more on “high-quality investment” like green finance, risk management tools, etc.

Most BRI routes, including emerging markets, are rich in coal, natural gas, and other mineral resources. According to the Statistical Review of World Energy (2020),¹ the total proven BRI reserves of three representative fossil fuels, including coal, natural gas, and oil, are approximately 59%, 54%, and 80% of the world’s total reserves. In addition, the average growth rates of total energy consumption and CO₂ emissions (CE) in the BRI countries are 5%, higher than the world’s average growth rate (5% and 3%). Not surprisingly, the BRI share of total energy consumption and CEs has increased from 39% to 43% in 2002 to 57% and 61% in 2018. To this end, severe environmental issues caused by excessive energy and resource consumption have posed significant challenges to BRI countries’ green development (GD)² (Aung et al., 2020). Therefore, adjusting the energy mix and seeking pathways are increasingly urgent for the BRI countries to achieve GD.

Undoubtedly, abundant natural resource (NR) is an “ideal prerequisite” for business operations and livelihoods; the reasonable depletion and utilization of NRs also play an essential role in achieving GD (Tao et al., 2024b). Thus, the question of whether the affluence of natural resource dependence (NRD) means a curse or a blessing to GD in the BRI countries needs further investigation. Past studies hold opposite standpoints on NRD’s effect. Supporting literature argued that affluent NR is important in reducing fossil energy imports, decreasing CEs, and attracting foreign direct investment (Balsalobre-Lorente et al., 2018). For example, Liu et al. (2022) found that NRD positively affected GD in Eastern China. Cheng et al. (2021) posited that implementing the Sustainable Development Plan of Resource-based cities in China effectively reversed the resource curse in resource-based cities. The same findings also can be detected in the seminal work of Lee and He (2022). In contrast, opposite viewpoints highlighted that regions with abundant NRs developed resource-insensitive industrial sectors (Mao et al., 2021). The high resource dependency tends to crowd out some crucial drivers of sustaining GD (Li et al., 2019), including weakening green technology innovation capability (Li et al., 2022), and distorting institutional quality (Shen et al., 2021). Wang et al. (2022) mentioned that NRD had a restricting effect on China’s energy efficiency improvement through technology innovation, human capital advancement, and degree of openness. The same conclusions are also identified in the work of Cheng et al. (2021), who believed that resource-based cities experience sluggish growth in green economic development.

The theoretical argument should be dated back to Adam Smith and David Richard, who argued that NR wealth sustains economic growth (Smith, 2024). This viewpoint is verified by the latter researchers, who also believed that resource-dependent countries outperform resource-poor countries (Auty and Mikesell, 1999; Findlay and Lundahl, 2001). Conventional economic theories regard NR as a “windfall” for a region, as abundant NRs can foster economic growth. NR’s discovery and utilization can bring a bonus to drive economic growth on the one

hand; on the other hand, the exploitation of NR will increase income levels and accelerate future economic development. However, some studies disputed this argument and concluded that resource-abundant countries did not enjoy higher economic growth than resource-poor countries. For instance, Che and Wang (2022) adopted resource economic dependence (RED) and resource employment dependence (RTD) to assess China’s NRD level. They further concluded that NRs expressed by RCD and RTD significantly adversely affected carbon emissions intensity, with the carbon curse hypothesis being more significant in resource-based cities. Zhu and Lin (2022) concluded that NRD has a lock-in effect on industrial structure transformation in China’s 283 cities, which, in turn, causes the dilemma that it is hard for China to adjust the secondary-oriented industrial structure. In addition, studies in Sub-Saharan Africa also verified the presence of the resource curse hypothesis (Hammond, 2011; Dartey-Baah et al., 2014).

Since the seminal studies of Gelb (1988) and Auty (1993), many works have found that NRD negatively affects economic growth. The mechanisms through which the resource curse occurs include four channels, such as “Dutch disease,” “pull effect,” “poor institutional quality,” and “fluctuating nature of natural resource good prices.”

The “Dutch disease” posits that the exports of NRs may result in the appreciation of the domestic currency, making the exports of other products from the non-natural resource departments expensive and losing core competitiveness on the international market (Gylfason, 2001). The “push effect” argues that the exploitation of NRs in an economy exerts adverse effects on other sectors’ development because NR sectors will absorb production factors such as labour, land, and other scarce resources. This may cause malicious competition and, therefore, increase the prices of these production factors. The discovery of NR may also weaken institutional quality, triggering political instability and severe corruption. This phenomenon may occur because incumbent government officials tend to gain personal interests through bribery. Notably, such a phenomenon is particularly prominent in emerging markets, where anti-corruption efforts are insufficient. Concerning Davis and Tilton (2005), the “volatility of NR commodity prices” may produce economic uncertainty, distort budgetary planning, and ultimately negatively affect economic growth.

Based on the above-stylized facts, a comprehensive investigation into the empirical nexus between NRD and GD is warranted in the 66 selected BRI countries. Such exploration will allow policymakers to accurately formulate their policies to mitigate CEs and promote sustainable use of NR, thereby boosting GD. In short, the distinct contribution of this paper is concluded as follows. First, this study proposes the green development curse hypothesis for the first time by conducting a systematic theoretical analysis. The logic behind this new hypothesis is that compared with the resource curse or carbon curse hypothesis, the proposed green development curse hypothesis highlights NRD’s effect on GD instead of carbon intensity or traditional economic growth. Extending the related theories, this hypothesis tries to achieve a “win-win” situation between energy saving and pollution mitigation. Second, current research has validated the resource curse hypothesis, which is used mainly for studies in China. Unfortunately, the relevant studies regarding the BRI countries are relatively scant.

Further, the benchmark regression is implemented based on an IV-estimation strategy to verify the occurrence of the green development curse hypothesis in the BRI countries, thereby yielding more convincing results and policy implications. Third, an IV-based three-step mediation effect model is adopted to investigate the underlying channels through which NRD affects GD, which have been comprehensively explored from the perspectives of technology innovation, institutional quality, population density, and human capital. Lastly, a novelty dynamic panel threshold model incorporating a two-step System generalized method of moment (SYS-GMM) and handling endogeneity is used to model a possible nonlinear relationship between NRD and GD under the four mechanisms above variables. In addition, we also validate the heterogeneous effect based on two perspectives: countries with different

¹ See <https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy/primary-energy.html>.

² GD is a sustainable development road and pattern featured by high energy efficiency, low pollution emissions, as well as high-level environmental management and governance (Xu et al., 2022).

environmental regulation levels and whether an individual belongs to a resource-based country.

Lastly, this study elaborates on how our analytical framework relates to the special issue by focusing on two aspects. First, NRD, which suggests the economy's reliance on extracting and exporting natural resources such as minerals and oil, is closely related to the SDGs. Specifically, extractive industries have substantial environmental implications, including deforestation, water pollution, and emissions. Unsustainable resource extraction exacerbates environmental degradation and threatens biodiversity, ecosystem services, and climate stability. Transitioning to more sustainable resource management practices, such as conservation, restoration, and renewable development, is instrumental in attaining SDGs related to environmental sustainability, climate action, and ecosystem protection. Second, improving GD (which is proxied by efficiency measurement) lowers the carbon intensity of energy production and consumption. By using energy more efficiently, countries can produce the same output level with fewer emissions, leading to a more carbon-efficient economy. This shift towards lower-carbon energy systems is pivotal for achieving carbon-peaking targets and transitioning to a sustainable, low-carbon future. Notably, these two aspects are, of course, included in the special issue scope.

The remainder of this paper is structured as follows. Section 2 develops the theoretical underpinnings. Section 3 describes the methodology. Section 4 reports the empirical findings. Section 5 conducts the mechanism analysis and heterogeneous analysis. Section 6 reports concluding and derives policy implications.

2. Theoretical underpinnings

2.1. Green development curse hypothesis

Again, NRs are necessary to support human and basic production activities. Unfortunately, the resource curse hypothesis uncovers that overdependence on NRs hinders economic growth by crowding out crucial drivers that significantly contribute to economic development, such as technology innovation (TI), institutional quality (IQ), population density (PD), and human capital (HC). First, the “Dutch disease” has usually been adopted by scholars as a cut-off point to address the channels through which the resource curse hypothesis may occur (Iimi, 2007). Specifically, the “Dutch disease” states that resource-abundant countries usually focus on expatriating and exporting NRs. This results in the actual exchange rate volatility, making exports from other industrial sectors uncompetitive. This may have fundamental implications for the BRI countries as they most concentrate on exporting NRs, which has caused a fragile ecological environment (Yan et al., 2022). Second, driven by the “pull effect,” various production factors will be absorbed by the NR sector from other departments, increasing the prices of the domestic production factors, which eventually increases production costs. Under such a situation, the distribution of production factors no longer aligns with the economic theory that production factors will be channelled from low-productivity sectors to high-level ones. This leads to resource misallocation between countries and has dire ramifications for GD (Hao et al., 2020). Third, the prosperity of resource-based industrial sectors triggers rent-seeking activities and corruption, which damage institutional structures. Worse, poor IQ leads to resource misallocation and decreased energy efficiency. For example, state-owned enterprises (SOE) lack innovative capability compared to private enterprises. Market players from SOEs may bribe local government officials for their interests, seeking less supervision and oversight and more returns (Holcombe and Boudreaux, 2015). Lastly, resource-rich countries experience tremendous fluctuations in natural resource prices, significantly challenging macroeconomic operations, and disturbing policy implementation (Xie and Zhi, 2020).

In short, NRD impedes sustainable economic growth in the long run and increases pollution emissions through multiple channels. Traditional productivity is a portion that cannot be explained by the number

of production factor inputs used in the final production process. Therefore, the Solow residual is applied to measure productivity as a standard measurement. With global climate change, countries emphasize addressing environmental issues and decreasing greenhouse gas emissions (GHG). Thus, the traditional definition of productivity may lose its power in the context of environmental protection and energy conservation. The proposed GD measure in this study goes beyond the conventional productivity concept. It will be considered a comprehensive measure considering economic growth, environmental protection, and energy utilization. Therefore, a thorough study on GD is urgently needed to adopt cleaner development patterns for the BRI countries, where economic growth can be continuously maintained. At the same time, a balance between energy conservation and pollution reduction can be sought, and other economies can be encouraged to prioritize green and inclusive development. To this end, this paper proposes the green development curse hypothesis.

Hypothesis 1. NRD can impede GD in the BRI countries.

2.2. Mechanism discussions

Figure 1 provides the graphical representation of the mechanism analysis. It is argued that the presence of the green development curse is not purely shocked by NRD. Therefore, we address the transmission paths between NRD and GD from the following perspectives: TI, IQ, PD, and HC.³

2.2.1. Crowding out TI & HC⁴

TI is not only a crucial driver for the development of human society but also plays a pivotal role in improving economic productivity and boosting GD (Jiang et al., 2021). Current studies provided empirical evidence to demonstrate the promoting effect of TI in stimulating GD. For example, Khan et al. (2020) pointed out that TI helped BRI countries to reduce CEs, thereby fostering economic growth. Instead, TI may also produce a “rebound effect” on GD (Ai et al., 2020). TI could increase the production volume; subsequently, a sharp increase in aggregate output means massive factor inputs, which leads to higher energy consumption and pollution emissions. It is noted that traditional natural resource exploitation sectors, such as coal and mining, lack innovative capability, and their motivation for conducting R&D activities is also insufficient. If countries only focus on developing these sectors, then the overall efficiency improvement of an economy will be limited. Concisely, overdependence on NRs hinders regions from gaining the requisite elements to facilitate TI. For instance, findings documented that areas with higher resource dependence have lower R&D investment (Papyrakis and Gerlagh, 2007), and the shrinking of the manufacturing industry is likely to occur in areas with an increase of resource dependence (Gylfason and Zoega, 2006). Nonetheless, Dong et al. (2022) asserted that NRD depresses TI in two ways. First, it is difficult for regions to proactively promote the diversification of their industries because the resource-based regions are heavily contingent on the NR sector to acquire economic gains, such as increasing income levels and obtaining various financial resources (Dogan et al., 2020). Second, excessive resource dependence in regions triggers a political lock-in effect, thus depressing the sustainable development of regional institutions. Therefore, we hypothesize.

³ Recall TI, IQ, PD and HC. Stand for Technological Innovation, Institutional Quality, Population Density and Human Capital.

⁴ We shall simultaneously combine TI with HC to carry out discussions because Danquah and Amankwah-Amoah (2017) highlighted that HC's advancement tends to facilitate the adoption of technology. Sabadie (2014) complemented that HC and other new social behaviours play essential roles in combining economic competitiveness and sustainability. This is because technology alone is no longer able to solve global challenges.

Hypothesis 2. NRD can depress GD in the BRI countries by crowding out TI.

HC advancement is vital for sustaining economic growth. Referring to Wang et al. (2021), HC significantly contributes to GD by accelerating technological progress, promoting knowledge ‘spillovers,’ matching the advancement of industrial structure, and enhancing people’s awareness of GD.

However, researchers argue that resource-rich countries tend to lack HC and consider the crowding-out effect of NRD on HC. As Shao and Yang (2014) posited, the expected income does not compensate for HC investment, and therefore, households’ desire for educational investment declines in resource-based countries. Consequently, this situation will result in a lack of more advanced HC accumulation. Additionally, expanding primary industry does not require a high-skilled labour force. Therefore, the demand for high-quality education declines, and with it, returns on education, thus diverting growth-improving investment from educational development (Gylfason, 2001). This paper, therefore, proposes the following hypotheses.

Hypothesis 3. NRD can depress GD in the BRI countries by crowding out HC.

2.2.2. Reducing PD

Theoretically, the concentration of population, as a compact spatial economic phenomenon, is coupled with several positive externalities that favour the economies-of-scale effect (Chen et al., 2022). The possible pathway in which the concentration of population is helpful to enhance energy utilization of factor inputs by knowledge diffusing effect or knowledge spillovers, which helps to decrease pollution emissions (Yu and Huang, 2022). Triggered by the scale effect (Shao et al., 2017), the concentration of the urban population will raise excessive energy demands and thus emit more pollution eventually. In addition, the population is often shrinking in resource-abundant regions because of HC outflow and the sluggish growth of industrial structure re-articulation (Bonilla Mejía, 2020). In addition, the fluctuation of NR commodity prices may cause inevitable consequences, such as a high employment rate and political and social instability (Zhang et al., 2022). These consequences will exacerbate population loss and thus show a downward trend in PD in resource-rich areas. Accordingly, the following hypothesis is derived.

Hypothesis 4. NRD can depress GD in BRI countries by reducing PD.

2.2.3. Disturbing IQ

GD aims to maximize economic benefits with minimal energy consumption and ecological deterioration (Song et al., 2019). Considering NR’s property (i.e., state-owned) and the negative externalities of pollution, the government’s intervention and participation are therefore indispensable for achieving GD. However, the government’s intervention and its power decentralization are influenced by the maturity of one country’s institutional structures, such as corruption control and political stability (Alsaleh et al., 2021). Undoubtedly, high-level IQ means efficient, powerful government and effective government decentralization. In contrast, in a flawed institutional system, firms are motivated to seek shelter for excessive NR consumption (Zhang et al., 2015). In other words, low corruption control makes the government an umbrella of enterprises with high-polluting emissions, thereby hindering GD. Without this background, the higher the NRD and the fewer environmental regulatory constraints firms face, the more excellent the opportunity for NR abuse, causing resource waste and increasing pollution emissions. Hence, hypothesis 5 is proposed as follows.

Hypothesis 5. NRD can depress GD in the BRI countries by damaging IQ.

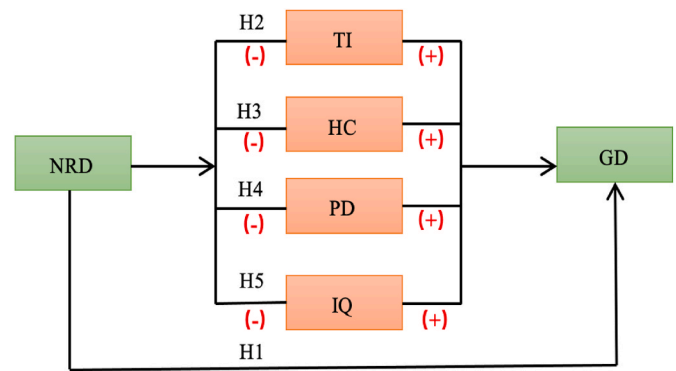


Fig. 1. Graphical representation of the theoretical hypotheses.

3. Methodology

3.1. Model setting

To validate the green development curse/blessing hypothesis in the BRI countries, this study first considers the following specification to model the effect of NRD on GD.

$$\ln GD_{it} = \beta_0 + \beta_1 \ln NRD_{it} + \beta_2 Z_{it} + \mu_i^a + \lambda_t^a + \varepsilon_{it}^a \quad (1)$$

where $\ln GD_{it}$ is the logarithmic green development of country i at year t ; $\ln NRD_{it}$ means the logarithmic natural resource dependence; Z_{it} is a set of interference variables; β_0 is an intercept; μ_i^a and λ_t^a are country fixed effect and time-period fixed effect, respectively; ε_{it}^a is an error term; β_1 and β_2 regression coefficients to be estimated.

This study further verifies the proposed H1 – H5 by constructing a mediation effect model. Based on Eq. (1), a three-step mediation effect model is further built to verify the underlying channels from four distinct perspectives: TI, HC, PD, and IQ. Remarkably, the models take the following form.

$$M_{it} = \gamma_0 + \gamma_1 \ln NRD_{it} + \beta_2 Z_{it} + \mu_i^b + \lambda_t^b + \varepsilon_{it}^b \quad (2)$$

$$\ln GD_{it} = \theta_0 + \theta_1 \ln NRD_{it} + \theta_2 M_{it} + \beta_2 Z_{it} + \mu_i^c + \lambda_t^c + \varepsilon_{it}^c \quad (3)$$

where M denotes the selected mechanism variables, including TI, IQ, PD and HC; μ_i^b and μ_i^c represent country fixed effects; λ_t^b and λ_t^c are time-period fixed effects; ε_{it}^b and ε_{it}^c are the random error terms; γ_0 – γ_1 and θ_0 – θ_2 are parameters to be determined. Specifically, this study runs a central variable, $\ln NRD$, against the selected mediators, as depicted in Eq. (2), to check their correlation. Then, mediators and $\ln NRD$ are included in Eq. (3) to check the corresponding effects, which are captured by parameters θ_2 and θ_1 . If these parameters are significant, confirm the potential mediating effects.

3.2. Dynamic panel threshold (DPT) model

Following the traditional panel threshold model developed by (Tao et al., 2023; Tao. et al., 2024a) and , a DPT model handling possible endogeneity is employed by this paper to explore the nonlinear nexus between NRD and GD. Specifically, the DPT model in this paper is regulated as

$$\ln GD_{it} = \beta_0 + \beta_1 \ln GD_{it-1} + \beta_2 \ln NRD_{it} \cdot I(q_{it} \leq \kappa) + \beta_3 \ln NRD_{it} \cdot I(q_{it} > \kappa) + \beta_4 Z_{it} + \mu_i^a + \lambda_t^a + \varepsilon_{it}^a \quad (4)$$

where $\ln GD_{it-1}$ represents the lagged period of GD; q_{it} denotes the regime-switching variables, including TI, IQ, PD, and HC. $I(\bullet)$ is an indicator function, and κ refers to the threshold value to be identified.

3.3. Variables and data sources

3.3.1. Dependent variable

GD is a dependent variable. The directional distance function model is used to assess country-level GD performance. Specifically, we take capital (K), labour (L), and energy consumption (E) as inputs. Gross domestic product (GDP) is treated as a desirable output, whereas country-level CE_s belong to unexpected output (Tao, 2024). Therefore, the production function is specified as

$$PF = \{(K, L, E, Y, CO_2) : (K, L) \text{ produce } (Y, CO_2)\} \quad (5)$$

Subsequently, the production technology can be arranged as follows

$$PT = \left\{ (K, L, E, Y, CO_2) : \sum_{n=1}^N z_n K_n \leq K, \sum_{n=1}^N z_n L_n \leq L, \sum_{n=1}^N z_n E_n \leq E, \right. \\ \left. \sum_{n=1}^N z_n Y_n \geq Y, \sum_{n=1}^N z_n CO_{2n} = CO_2 \right\} \quad (6)$$

In Eq. (6), z_n means the intensity variable that input and output factors to form a convex set $z_n \geq 0, n = 1, \dots, N$.

The non-radical DDF function is defined as follows

$$\overline{\text{non-DDF}}(K, L, E, Y, CO_2; g) = \sup \{ \omega^T \delta : [(K, L, E, Y, CO_2) + g \bullet \text{diag}(\delta)] \in T \} \quad (7)$$

Where $\text{diag}(\delta)$ denotes the diagonal matrix; $\omega^T = (\omega_K, \omega_L, \omega_E, \omega_Y, \omega_{CO_2})^T$ is the standardized weight vector of all variables; $g = (-g_K, -g_L, -g_E, g_Y, -g_{CO_2})$ refers to the directional vector; $\delta = (\delta_K, \delta_L, \delta_E, \delta_Y, \delta_{CO_2})$ is the proportional vector representing the deviation of all variables. Subsequently, the DEA model can be established.

$$\overline{\text{non-DDF}}(K, L, E, Y, CO_2; g) = \max \{ \omega_K \delta_K + \omega_L \delta_L + \omega_E \delta_E + \omega_Y \delta_Y + \omega_{CO_2} \delta_{CO_2} \} \\ \text{s.t. } \sum_{n=1}^N z_n K_n \leq K - z_n K_n, \sum_{n=1}^N z_n L_n \leq L - z_n L_n, \sum_{n=1}^N z_n E_n \leq E - z_n E_n, \\ \sum_{n=1}^N z_n Y_n \geq Y + z_n Y_n, \sum_{n=1}^N z_n CO_n = CO - z_n CO_{2n} \quad (8)$$

Referring to Zhang et al. (2014), the directional vector g and the weight vector ω are set as $g = (-g_K, -g_L, -g_E, g_Y, -g_{CO_2})$ and $\omega = \left(\frac{1}{9}, \frac{1}{9}, \frac{1}{9}, \frac{1}{3}, \frac{1}{3} \right)$, respectively. By estimating Eq. (8), the optimal solution $\delta_K^*, \delta_L^*, \delta_E^*, \delta_Y^*$, and $\delta_{CO_2}^*$ can be reached. Therefore, country-level GD can be calculated by adopting Eq. (9).

$$GD = 1 - \overline{\text{non-DDF}}(K, L, E, Y, CO_2; g) \quad (9)$$

3.3.2. Key independent variable

NRD is the key independent variable. NRs give rise to economic rents because they are not produced, and this indicator mainly reflects the quantity of NRs that a country processes. NRD is proxied by the share of the rent of natural resources to GDP (Haseeb et al., 2021). According to the World Bank⁵, total NR rents are the sum of oil rents, natural gas rents, coal rents (including both hard), mineral rents, and forest rents. Past studies have proved the suitability and appropriateness of NR rents as a measure of NRD (Asiamah et al., 2022).

3.3.3. Control variables

According to the past literature, several control variables, including per capita GDP, urbanization, industrialization, financial development,

and foreign direct investment, are selected to rule out the effects of other variables on GD.

- (1) Per capita GDP (PGDP). This study incorporates PGDP and its quadratic form into Eq. (1) to verify the EKC hypothesis in the BRI countries.
- (2) Urbanization (URB). The rapid expansion of the scale of towns and cities facilitated by population accumulation is not an uncommon phenomenon of spontaneous population mitigation or labour mobility but the result of profound social and economic development changes. The traditional urbanization model is promoted based on the extensive development model, which raises environmental issues and lowers energy efficiency. In contrast, empirical evidence from existing studies demonstrates the promoting effect of new-type urbanization on GD (Shao and Wang, 2023; Feng et al., 2022). Precisely, URB is gauged by the share of the total urban population to the total population.
- (3) Industrialization (IND). IND is assessed by the industrial value added per unit of GDP. Developed economies with advanced industrial sectors are more efficient compared to emerging economies. Adjusting and transforming industrial structures with advanced technologies can help reduce pollution emissions and improve efficiency, thus contributing to GD.
- (4) Financial development (FD). FD is indexed by the bank's credit scale ratio to GDP. The promoting effect of FD on GD has been prominent in past studies. According to Nasir et al. (2019), FD reduces the costs of financial intermediations, diversifies risks, and enables the public and private sectors to invest more in green energy projects. GD can also be stimulated by attracting FDI inflows and inducing R&D activities (Frankel and Romer, 1999). Hence, FD's sustainable development is expected to promote GD in the BRI countries.
- (5) Foreign direct investment (FDI). FDI is represented by the net inflow of FDI in GDP. Triggered by the "pollution halo" hypothesis and the "pollution heaven" hypothesis, FDI can bring dual effects on GD. On the one hand, FDI promotes GD by bringing green technologies and absorbing advanced management experience through the learning effect (Kim et al., 2015) and the flow of professional talents. On the other hand, FDI hinders GD because some preferential policies could attract foreign enterprises with low innovative capability and high polluting emissions to participate in corresponding business activities in the domestic market, thus aggravating environmental quality (Shahbaz et al., 2015).

3.3.4. Mechanism variables

Following the theoretical underpinnings, the related discussion regarding mechanism variables follows.

- (1) Technology innovation (TI). TI is considered one of the most crucial elements in driving economic growth and promoting low-carbon sustainable economic development by lowering energy consumption, promoting industrial structure re-articulation, and reducing pollution emissions. The logarithm of patent applications represents TI.
- (2) Institutional quality (IQ).⁶ IQ in this study contains six indicators: voice and accountability, political stability and absence of violence/terrorism, government effectiveness, regulatory quality, the rule of law, and corruption control. To reflect the overall performance between decision-making units, a comprehensive score determined by the entropy method is used to express country-level IQ. The detailed procedures are as follows. Specifically, we first carry out a standardization process to normalize

⁵ See <https://www.worldbank.org/en/home>.

⁶ The data source of IQ is reported in section 3.3.6.

the raw data to ensure that each selected indicator is distributed in $[0, 1]$ by adopting $X_{ij} = \frac{\max(x_{ij}) - x_{ij}}{\max(x_{ij}) - \min(x_{ij})}$. Second, the proportion of each indicator is then determined by using $p_{ij} = x_{ij} / \sum_{i=1}^{66} x_{ij}$. Third, the entropy value of each indicator is calculated using $E_j = -\frac{1}{\ln(66)} \sum_{i=1}^{66} p_{ij} * \ln(p_{ij})$. Fourth, the coefficient variation of each indicator is determined by using $d_j = 1 - E_j$. Fifth, the weight of each indicator is as follows: $w_j = d_j / \sum_{j=1}^6 d_j$. And finally, a comprehensive score is derived to denote IQ by using $IQ = \sum_{j=1}^6 w_j * X_{ij}$. According to Ibrahim (2020), the ability to address environmental problems depends heavily on the country's IQ quality. Hence, a sound institutional system is conducive to realizing GD.

- (3) Population density (PD). The concentration of the population in a particular region is beneficial to improving GD through technology and knowledge spillovers (Yan and Huang, 2022). In contrast, the accumulation of the population can raise more energy demands, dampening GD. PD in this study is proxied by the total population per square kilometer.
- (4) Human capital (HC). HC is quantified by the years of schooling and returns to education. Following Hu 2021, HC plays a pivotal role in TI, and countries with advanced HC absorb advanced technologies. In essence, HC accumulation is a crucial source of technological progress. Still, highly educated HCs help develop environmentally friendly and energy-saving technologies (Ai et al., 2015). The more refined and advanced HC, the greater the chances that professional and technical personnel will support the commercialization of clean technologies.

3.3.5. Identification strategy

One of the most crucial concerns in this paper is how to address possible endogeneity when modelling the effect of NRD on GD in BRI countries. The endogeneity in this paper comes from two sources. First, although we have selected several control variables to rule out the shocks from other variables, the variable omission may exist in the benchmark regression model. The second issue is reverse causality. Countries characterized by energy-intensity development mode may lack effective measures and conditions for achieving green or inclusive transformation, which may render these countries locked in the development pathway with high NRD.

The instrument variable (IV) identification strategy is applied to conduct an empirical analysis to overcome the possible endogeneity and obtain accurate estimates. Theoretically, a reasonable IV should satisfy the following requirements: exogeneity and relevance. For simplicity, the selected IV should be corrected with an endogenous variable and only produce a particular effect on the dependent variable through the endogenous variable. However, IV's selection is challenging at the country level due to the unavailability of data. Fortunately, one country's land area (LA) can be considered a successful trial for solving endogeneity. On the one hand, Zhao (1986) pointed out that metallic minerals were mainly distributed in mountains and plateaus, while basins and plains are mostly agglomerations of sedimentary minerals. This means that the resource endowments of one country may vary from its geographical location. Therefore, NRD's distribution is closely associated with LA. On the other hand, the country's LA is rarely influenced by human activities in peacetime. Thus, the exogeneity is also satisfied.

It is also noteworthy to posit that LA is a typical time-invariant variable; we follow the seminal work of Duflo and Pande (2007) to match our dataset. Specifically, we establish a time-varying IV by multiplying LA with the relative effective exchange rate index (REERI). There are two reasons for employing REERI as a multiplier. Notably, REERI stratifies the exogeneity because it is hard to be directly affected by GD at a country level. At the same time, REERI's fluctuations could exert a specific effect on NRD by influencing various energy prices and

the exploitation of natural resources such as mining and coal.

3.3.6. Data sources

Our research sample includes 66 BRI countries spanning from 2005 to 2019. Appendix A lists the selected 66 BRI countries. More specifically, data concerning HC are collected from PWT 10.0. Data regarding IQ are extracted from the Worldwide Governance Index. The input and output data for measuring country-level GD and other variables are directly collected from the World Bank database. Table 1 reports the descriptive statistics of all variables. Before conducting empirical analysis, all variables have been converted into the natural logarithm to avoid possible heteroscedasticity. The data regarding GD and NRD is depicted in Fig. 2.

4. Empirical findings

4.1. Baseline regression

The Breusch-Pagan LM test (Breusch and Pagan, 1980) checks potential spatial dependence between cross-sections for all cross-sectional units. The corresponding statistic is 7.392 (p -value = 0.000), which rejects the null hypothesis. In other words, there is no cross-sectional dependence issue within the dataset. Fig. 3 displays the correlation between logarithm NRD and logarithm GD in the BRI countries. Intuitively, a significant negative correlation between the two variables is identified.

Subsequently, Eq. (1) is used to examine the effect of NRD on GD by implementing an IV-estimation strategy. We observe the changes in NRD's coefficients by sequentially adding control variables. As presented in Table 2, all columns' KP rk LM statistics strongly reject the original assumption of under-identification, meaning that the constructed IV significantly correlates with endogenous variables. Therefore, the relevance requirement is satisfied. At the same time, the first-stage F-statistics in columns (1)–(7) are more significant than the critical value ten based on the rule of thumb, thus rejecting the original assumption of weak IV assumptions. In short, the IV's construction and the implementation of the IV-estimation strategy in this paper are credible. Overall, there are no significant fluctuations concerning the NRD's absolute magnitude and saliency. The estimated coefficient of NRD is -0.0855 after controlling all the selected interference variables, suggesting that every 1% increase in NRD will reduce GD by approximately 0.0855% on average (column (7)). The results preliminarily certify the green development curse hypothesis in the BRI countries. Hypothesis 1 is thus confirmed.

However, one could also envisage time-varying effects in the NRD-GD relationship. Therefore, we examine their causal links by focusing on heterogeneous years. As displayed in Fig. 4, the corresponding estimates of NRD are visualized in this study. Intuitively, there is substantial heterogeneity between the two in terms of magnitude and directionality. Specifically, the dampening effect of NRD tends to increase with the year, with the associated dampening effect being particularly pronounced between 2010 and 2013. In contrast, the limiting effect remains relatively weak in other years and even turns positive in 2017, but these effects are insignificant. This finding supports that NRD has produced weakly depressing implications on GD since 2014. This result confirms that the dampening effect of NRD on GD has been somewhat fainter since 2014, implying that the unfavorable impact is expected to weaken in the BRI countries.

As for interference variables, first, the coefficient of PGDP is significantly negative, but its quadratic form is positive at a 1% significance level, meaning that with economic expansion, the environmental quality tends to be worsened in the BRI countries. This finding aligns with Li et al., 2022, who stated that the EKC hypothesis remains invalid in the BRI countries. The possible explanation is that over 70% of the BRI countries are lower-middle-income economies, and the inflection point (or the threshold) on the EKC may not have occurred yet. Second,

Table 1
Descriptive statistics.

category	variable	unit	obs	mean	sd	min	max
Dependent variable	lnGD	/	990	−0.289	0.082	−0.392	0.000
Key independent variable	lnNRD	%	990	−4.814	2.305	−13.733	−0.820
Interference variables	lnPGDP	2010 US\$	990	9.053	1.352	6.447	11.63
	lnURB	%	990	1.804	0.395	0.599	2.303
	lnIND	%	990	−1.353	0.270	−2.261	−0.414
	lnFD	%	990	−0.772	0.812	−2.721	1.114
	lnFDI	%	990	−3.504	1.152	−10.999	−0.207
Mechanism variables	lnIQ	/	990	−0.852	0.590	−3.004	−0.039
	lnHC	/	990	0.975	0.258	0.304	1.471
	lnPD	People/sq • km	990	−0.283	1.363	−3.749	4.378
	lnTI	Piece	990	7.543	2.684	1.797	13.287

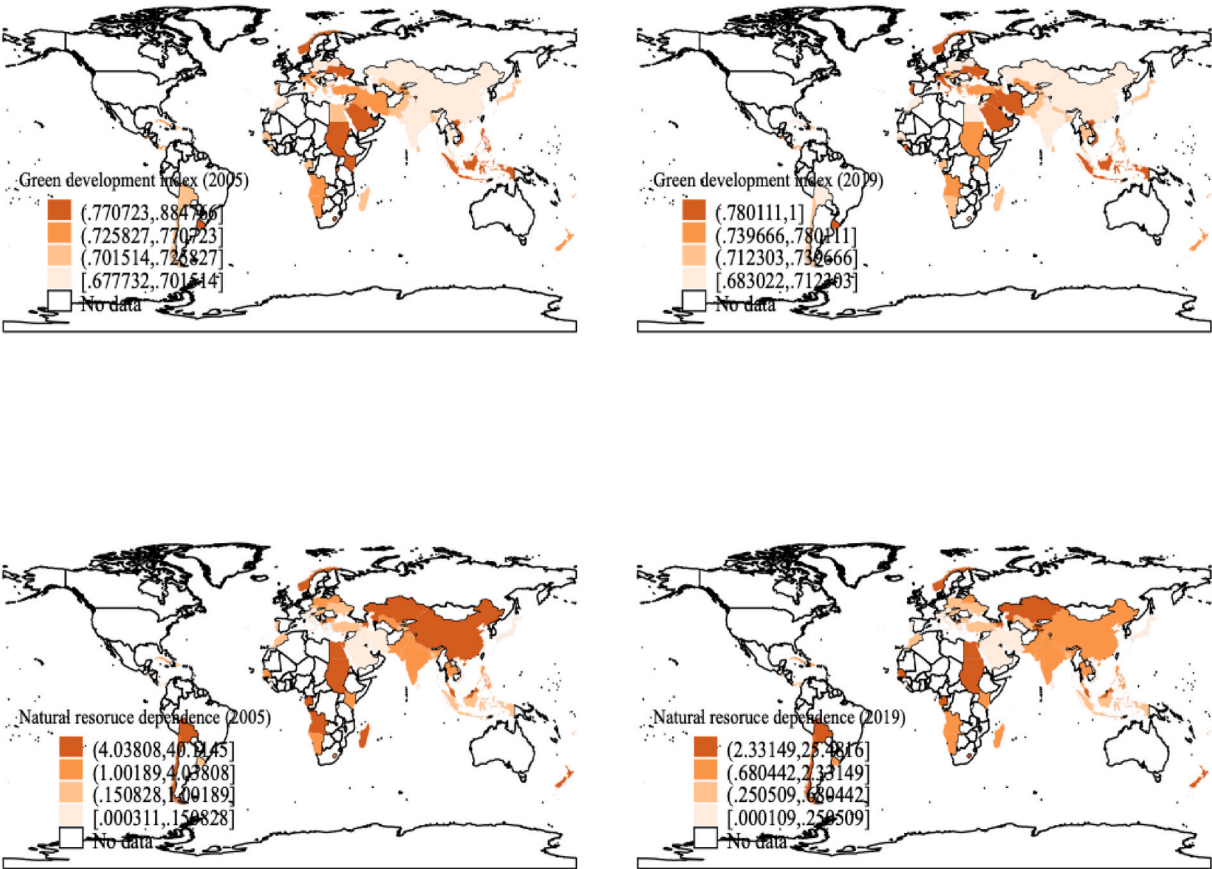


Fig. 2. NRD and GD indexes in the BRI countries in the selected years.

urbanization negatively affects GD. Again, the traditional urbanization mode has triggered environmental issues: ecological damage, haze pollution, rapid urban population agglomeration, and increasing demand for energy consumption. That is why countries worldwide emphasize establishing a new-type of urbanization. Third, the industrialization process produces a weak positive effect on GD. There is no denying that industrialization creates material wealth, increases people's wealth, and promotes economic growth, and economic growth will lose power without structural changes (i.e., structural dividend hypothesis). Concisely, the re-articulation of countries' industrial structures is redistributing production factors. Undoubtedly, the continuous optimization of the industrial structure can boost GD (Haraguchi et al., 2019). Fourth, FD has a weak promoting effect on GD. Specifically, the promoting effect of FD on GD includes three effects: scale effect, structural effect, and technological effect. More importantly, FD can optimize the economic structure, reduce excessive energy consumption, and force relevant participants to adopt cleaner equipment for business activities (Sadorsky, 2010). Lastly, the "pollution heaven" hypothesis is captured

in the BRI countries as FDI's coefficient is negative and passes the significance test of 1%.

One may also envisage the time-varying effects regarding the RG-GD nexus. We thus check the causal relationship between them by focusing on heterogeneous years. This study visualizes the corresponding estimates of RG, as depicted in Fig. 4. Intuitively, there is substantial heterogeneity regarding magnitude and directionality.

4.2. Robustness checks

This paper conducts a set of robustness tests to verify the feasibility of the benchmark regression results.

- (1) *Replacing the explained variable.* To check the feasibility of the results, we assume that the inputs of decision-making units at the frontiers and then re-estimate GD, expressed as GD1. More specifically, the directional vector as $g = (0, 0, 0, -g_{CO2})$ and weight

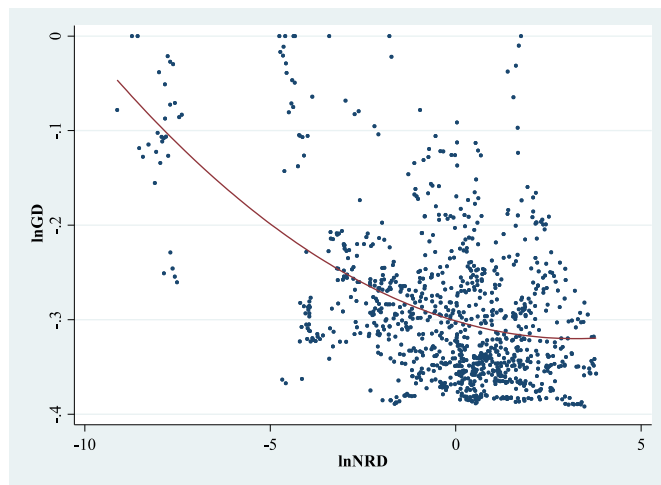


Fig. 3. The correlation between logarithm NRD and logarithm GD in the BRI countries. Notes: The X-axis represents the logarithmic natural resource dependence index, and the Y-axis denotes the logarithmic green development index.

vector are set as $\varpi = (0, 0, 0, \frac{1}{3})$ to assume the index related to the efficiency of unexpected output when the inputs maintain unchanged. Then, the calculation strategy of non-DDF related to GD1 is

$$\begin{aligned} \text{non-DDF}_{\text{GD1}}(K, L, E, Y, \text{CO}_2; g) &= \max\{\varpi_{\text{CO}_2} \delta_{\text{CO}_2}\} \\ \text{s.t. } \sum_{n=1}^N z_n K_n &\leq K, \sum_{n=1}^N z_n L_n \leq L, \sum_{n=1}^N z_n E_n \leq E, \\ \sum_{n=1}^N z_n Y_n &\geq Y, \sum_{n=1}^N z_n \text{CO}_n = \text{CO} - z_n \text{CO}_{2n} \end{aligned} \quad (10)$$

Table 2
Baseline regression results.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Dependent variable: lnGD							
lnNRD	-0.0813 ^c (0.022)	-0.0775 ^c (0.019)	-0.0677 ^c (0.018)	-0.0796 ^c (0.024)	-0.0796 ^c (0.024)	-0.0834 ^c (0.028)	-0.0855 ^c (0.028)
LnPGDP		-0.0149 (0.015)	-0.3653 ^c (0.092)	-0.1731 (0.150)	-0.1821 (0.141)	-0.2721 ^b (0.125)	-0.3052 ^b (0.125)
lnPGDP2			0.0210 ^c (0.006)	0.0119 (0.008)	0.0123 (0.008)	0.0169 ^b (0.007)	0.0186 ^c (0.007)
lnURB				-0.2060 ^b (0.096)	-0.1976 ^b (0.085)	-0.2048 ^b (0.092)	-0.2091 ^b (0.094)
lnIND					0.0133 (0.028)	0.0265 (0.037)	0.0384 (0.039)
lnFD						0.0172 (0.014)	0.0207 (0.015)
lnFDI							-0.0076 ^{***} (0.002)
KP rk LM statistic	17.203 (0.000)	21.830 (0.000)	20.004 (0.000)	13.830 (0.000)	13.968 (0.000)	11.805 (0.000)	11.588 (0.000)
Country fixed effect	✓	✓	✓	✓	✓	✓	✓
Year fixed effect	✓	✓	✓	✓	✓	✓	✓
Obs.	990	990	990	990	990	990	990
1st stage regression							
Dependent variable: lnNRD							
ln(LA * REERI)	-0.5715 ^c (0.140)	-0.5828 ^c (0.140)	-0.5611 ^c (0.140)	-0.5056 ^c (0.141)	-0.5015 ^c (0.140)	-0.5057 ^c (0.141)	-0.5023 ^c (0.140)
Interference variables	✓	✓	✓	✓	✓	✓	✓
F statistics	16.705	17.260	16.065	12.794	12.920	12.794	12.995

Notes: Figures reported in (.) represent standard errors.

p < 0.10.

p < 0.50.

p < 0.01.

Eq. (11) is used to calculate GD1.

$$\text{GD} = 1 - \text{non-DDF}_{\text{CO}_2}(K, L, E, Y, \text{CO}_2; g) \quad (11)$$

As shown in column (1) of Table 3, the KP rk LM statistic is 12.880, which rejects the original assumption of under-identification; simultaneously, the first-stage F-statistic is also significant. This shows that the constructed IV passes the weak IV test. NRD's coefficient is negative at a 1% significance level.

(2) *Changing estimation method.* The two-step SYS-GMM method is performed to re-run Eq. (1), as reported in column (2). The p-value of AR (2) is insignificant, suggesting no second-order serial autocorrelation. At the same time, the p-value of the Sargan test is

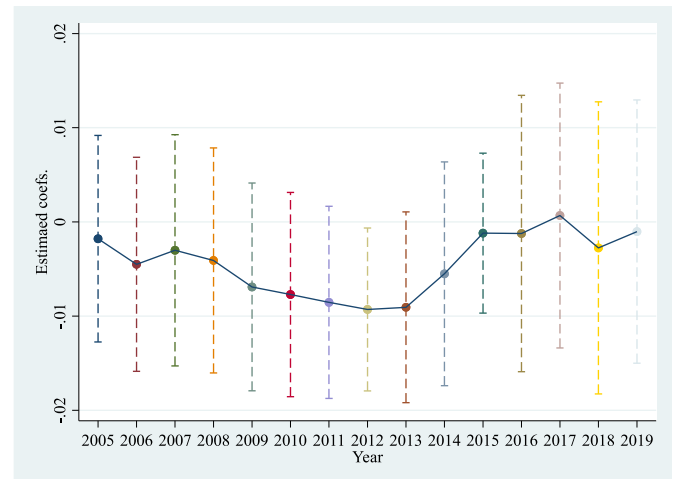


Fig. 4. Time-varying effects of NR on GD. Notes: The X-axis represents the specific years, and the Y-axis denotes the corresponding estimates.

more significant than 0.10, implying that the selected IV is effective. NRD's coefficient is also damaging at a 1% significance level.

- (3) *Alternative IV-estimation strategy.* A newly designed IV is established based on the heteroscedasticity in the random error term by following [Lewbel \(2012\)](#). The results in column (3) of [Table 3](#) also verify NRD's restricting effect on GD. Based on the above robustness tests, the green development curse hypothesis was shown to exist in the BRI countries.
- (4) Considering that the country-level NRD is a composite score that includes various rent alternatives, we also re-collected data on oil, coal, natural gas, minerals, and forests for a more robust validation to check whether the benchmarking results differ across rent alternatives. Fortunately, the different rent alternatives also depress the GD in the BRI countries (see [Appendix B](#)).

5. Mechanism analysis and heterogeneity verification

5.1. Mechanism analysis

The baseline regression results verify the green development curse hypothesis. However, the underlying channels in which NRD affects GD are unclear in the BRI countries. We further investigate the transmission mechanisms from TI, IQ, PD, and HC perspectives. As addressed in the methodology section, an IV-based three-step mediation effect model based on [Baron and Kenny \(1986\)](#) is employed.

- (1) Columns (1) & (2) in [Table 4](#) report the mediation effect results of TI. First, NRD produces a significant adverse effect on TI, with an estimated coefficient of -0.4902 . The coefficient of NRD becomes smaller after controlling TI, but it still has an inhibitory effect on GD, with TI having a strong promoting effect. Since parameter, θ_2 , the coefficient of the mediator is insignificant. Sobel test is applied to further check the feasibility of the

Table 3

Robustness results.

Dependent variable:	(1) lnGD _{it-1}	(2) lnGD	(3) lnGD
lnGD _{it-1}		0.3405 ^c (0.011)	
lnNRD	-0.6138^c (0.027)	-0.0015^c (0.001)	-0.0095^c (0.002)
KP rk LM statistic	12.880 (0.000)		79.419 (0.000)
Control variables	✓	✓	✓
Country fixed effect	✓	✓	✓
Year fixed effect	✓	✓	✓
Obs.	990	924	990
_cons		1.2733 ^c (0.094)	0.9435 ^c (0.091)
AR (1)		-1.8516 (0.0641)	
p-value			
AR (2)		1.321 (0.1865)	
p-value			
Sargan test		44.5894 (0.1828)	
p-value			
1st stage regression			
Dependent variable: lnNRD			
ln(LA * REERI)	-0.5023^c (0.140)		
Interference variables	✓	✓	✓
F statistics	12.880		109.829

Notes: Figures reported in(.) represent standard errors.

$p < 0.10$.

$p < 0.50$.

$p < 0.01$. lnGD_{it-1} represents the lagged values of lnGD.

Table 4

Mediating tests.

Panel A: Sobel test for TI				
	Coef.	Std. Err	z-value	p-value
Indirect effect (IE)	-0.0010^c	0.0002	-3.8395	0.0001
Direct effect (DE)	-0.0033^c	0.0010	-3.4261	0.0001
Total effect (TE)	-0.0043^c	0.0010	-4.4010	0.0000
The ratio of total effect that is mediated (PTE):			0.2339	
The ratio of indirect to direct effect (RID):			0.3053	
The ratio of total to indirect effect (RTI):			1.3053	
Panel B: Sobel test for IQ				
	Coef.	Std. Err	z-value	p-value
IE	0.0003 ^b	0.0002	2.0834	0.0372
DE	-0.0046^c	0.0010	-4.7445	0.000
TE	-0.0043^c	0.0010	-4.4006	0.000
PTE:			-0.0723	
RID:			-0.0674	
RTI:			0.9326	
Panel C: Sobel test for PD				
	Coef.	Std. Err	z-value	p-value
IE	0.0005	0.0005	1.0394	0.2986
DE	-0.0050^c	0.0011	-4.5822	0.000
TE	-0.0045^c	0.0010	-4.5760	0.000
PTE:			-0.1077	
RID:			-0.0972	
RTI:			0.9028	
Panel D: Sobel test for HC				
	Coef.	Std. Err	z-value	p-value
IE	0.0003 ^a	0.0001	1.9377	0.0527
DE	-0.0046^c	0.0010	-4.6471	0.000
TE	-0.0043^c	0.0010	-4.4006	0.000
PTE:			-0.0613	
RID:			-0.0577	
RTI:			0.9423	

Notes.

^a $p < 0.10$.

^b $p < 0.50$.

^c $p < 0.01$.

mediation results by following [Wen and Ye \(2014\)](#), as presented in [Table 4](#) (Panel A). The Sobel test results display that both direct and indirect effects of NRD on TI are significant at a 1% significance level. Simultaneously, the parameters of each path are also statistically significant, with the estimated coefficients of TI and NRD being -0.0043 (p -value = 0.000) and -0.0033 (p -value = 0.001). To this end, the mediation effect of TI is identified, and [Hypothesis 2](#) is verified. That is, NRD hinders GD in the BRI countries by weakening TI. Thus, [Hypothesis 2](#) is verified. As addressed by the endogenous growth theory, TI is an enabler for stimulating economic growth. In the meantime, modern economic studies also share wisdom to demonstrate the crucial role of TI, especially the sustainable development of green TI in the process of improving energy efficiency, combating climate change, and addressing environmental issues ([Lin and Ma \(2022\)](#); [Shao et al. \(2021\)](#); [Kuang et al. \(2022\)](#)). Hence, technological advancement is beneficial to achieve a low-carbon economic transition. However, the negative effect of NRD on TI verifies the crowding-out effect of NRD on TI (see column (1) of [Table 4](#)). To this end, weakening the inhibitory effect of NRD on TI and accelerating technological progress, especially the development of low-carbon green technologies, are pressing to eliminate the green development curse in the BRI countries.

- (2) The coefficient of NRD in column (3) is negative at a 5% significance level, suggesting that NRD weakens IQ in the BRI countries. Still, the results prove the partial mediation effect of IQ between NRD and GD because NRD's coefficient in column (4)

Table 5
Mechanism analysis results.

Dependent variable	(1) lnTI	(2) lnNRD	(3) lnIQ	(4) lnNRD	(5) lnPD	(6) lnNRD	(7) lnHC	(8) lnNRD
lnNRD	−0.4902 ^b (0.191)	−0.0856 ^c (0.028)	−0.0402 ^b (0.018)	−0.0848 ^c (0.030)	−0.2763 ^c (0.078)	−0.0828 ^c (0.026)	−0.0744 ^c (0.026)	−0.0658 ^c (0.025)
lnTI		0.0187 ^b (0.009)						
lnIQ				−0.0321** (0.015)				
lnPD						−0.0553 (0.046)		
lnHC								0.1510 ^c (0.056)
KP rk LM statistic	12.995 (0.000)	11.545 (0.000)	12.995 (0.000)	13.320 (0.000)	13.323 (0.000)	13.276 (0.000)	12.995 (0.000)	10.610 (0.000)
Country fixed effect	✓	✓	✓	✓	✓	✓	✓	✓
Year fixed effect	✓	✓	✓	✓	✓	✓	✓	✓
Obs.	990	990	990	990	990	990	990	990
1st stage regression								
Dependent variable: lnNRD								
ln(LA * REERI)	−0.5023 ^c (0.140)	−0.5023 ^c (0.140)	−0.5023 ^c (0.140)	−0.5083 ^c (0.140)	−0.5023 ^c (0.140)	−0.4080 ^c (0.150)	−0.5023 ^c (0.140)	−0.4565 ^c (0.141)
Interference variables	✓	✓	✓	✓	✓	✓	✓	✓
F statistics	12.880	11.590	12.880	13.193	12.880	13.401	12.880	10.477

Notes: Figures reported in(.)represent standard errors.

p < 0.10.

p < 0.50.

p < 0.01.

remains significantly negative when controlling IQ. For robustness check, Table 4 (Panel B) also reports the corresponding results estimated by the Sobel test, which aligns with previous results. To this end, Hypothesis 3 is supported. Notably, the role of IQ is also well documented in the existing literature. Theoretically, a high-level IQ indicates the country's institutional structure is relatively sound, which ensures the fluent implication of the related economic policies by creating a favorable economic environment. The empirical results deliver two crucial outcomes. First, the restricting effect of NRD on IQ to a certain extent may worsen institutional structures in the BRI countries. Second, the poor institutional structures caused by NRD's crowding-out impact may be a barrier to curbing GD improvement in the BRI countries. This claim is also consolidated by this paper's findings (referring to column (4) of Table 4).

- (3) Like TI, the results do not verify the mediation effect of PD between NRD and GD, but NRD can help reduce PD. (columns (5) & (6) of Table 4). Following the same methodology, we re-examine PD's meditation effect, as Table 4 (Panel C) documented. The results show that at least a 10% significance level, the indirect impact is insignificant. Therefore, Hypothesis 4 is rejected.⁷ The mainstream of economic agglomeration highlights that the concentration of population in a specific area can bring about clustering bonuses in the shorter run. Fortunately, such a bonus is indeed helpful in reducing pollutant emissions and stimulating economic growth (Yan and Huang, 2022). Consequently, the agglomeration effect will facilitate GD. According to He et al. (2017), economic slowdown often occurs in the later phase of

resource-based regions. It further reduces urban shrinkage because they follow the 'boom and bust' cycle. The fundamental reason is that the supply of natural resources heavily dependent on the resource-based industrial sectors for mass production is unsustainable. Therefore, the depletion of NRs will accelerate the urban shrinking effect and crowd out the population, thereby reducing PD.

- (4) Like IQ, HC has a partial mediation effect between NRD and GD. In the meantime, NRD plays an inhibitory role in HC advancement in the BRI countries. In contrast, as a crucial enabler, advanced HC promotes GD improvement (see column (8) of Table 5). Meanwhile, empirical results as an additional check also verify that NRD depresses GD in the BRI countries by crowding out HC. Thus, Hypothesis 5 is therefore confirmed. Based on the former discussions, resource-based regions will eventually lose competitiveness in the global market. Scarce resources will be shifted from these regions to other areas with high potential. These so-called high potential regions have significant incentives to conduct R&D activities and prioritize sustainable development, for example. Therefore, productivity will also gradually improve. In addition, advanced HCs, who are exceptionally professional talents, will participate in regions with high productivity levels because of the potential wage differentials. Therefore, the negative effect of NRD on HC is also verified.

5.2. Dynamic panel threshold model

Empirical findings from mechanism analysis show that TI, IQ, and HC have mediation effects between NRD and GD. In other words, NRD not only directly affects GD but also exerts an indirect inhibitory effect on GD by weakening innovative capability, disturbing institutional structures, and crowding out HC. At the same time, the mechanism analysis results also demonstrate that NRD can help to reduce PD. Although the mediation effect of PD is not supported from an econometric perspective, the concentration of the population plays a crucial role in fostering GD and, bearing in mind that the effect of NRD on GD may be subject to the development performance of TI, IQ, PD, and HC. Thus, Eq. (4) is adopted to model the nonlinear relationship between

⁷ We also adopt bootstrap method for further examination to check whether PD plays a mediation effect between NRD and GD. The motivations for performing bootstrap-based mediation test lie in two crucial aspects. First, Sobel test requires specific mediation and total mediation effects in the model should obey normal distribution. Second, Sobel test requires a large sample, and the specific effects should be calculated manually. However, the bootstrap-based mediation results also show that the indirect effect is indeed insignificant, with the value of being 0.0004 (p-value = 0.553).

NRD and GD under different mechanism variables.

The SYS-GMM method evaluates the difference equation and the horizontal equation as an equation, which improves the estimation accuracy on the one hand; on the other hand, it can also estimate the coefficients of all variables that do not change over time. Therefore, applying the two-step SYS-GMM method can yield more precise results than the differential GMM method. Besides, the bootstrap method is introduced to evaluate the probability of the threshold effect, which is based on 1000 times. Still, the 95% confidence interval of the threshold value is determined based on the pioneering work of Hansen (1999). The results from Table 6 reject the original assumption of no threshold effect as the p -values of the Wald statistics under different models are smaller than 0.10. Therefore, it is believed that NRD has a nonlinear impact on GD in the BRI countries.

The whole sample is then divided into two subgroups according to whether the estimated threshold variable surpasses the estimated threshold value. For comparison, Table 7 reports the grouping classifications in 2005 and 2019, respectively. As we can see, there is a substantial improvement in the mechanism variable in each subgroup. This outcome suggests that TI, IQ, and HC have been significantly facilitated; PD is also mitigated in BRI countries. However, the overall performance in some BRI countries, such as Bangladesh, Bolivia, Gabon, Namibia, Sudan, and Moldova, has not dramatically improved, and most of them belong to low- or lower-middle-income countries. Specifically, take 2009 as an example. When TI is treated as a threshold variable, 24 countries crossed 9.3428, accounting for 36.36% of the sample. The top five include Cyprus (12.2869), Uruguay (12.9267), India (11.9289), Italy (11.4778), and Turkey (11.4747). TI performance from 42 countries is less than 9.3428, with Kenya having the lowest value (2.7939). It is also mentioned that the bottom ten with the lowest TI performance contain five high-level-income countries (i.e., Niger, Fiji, Ukraine, Madagascar, Seychelle, Croatia), three upper-middle-income countries (Gambia, Madagascar, Egypt) and two lower-middle-income countries (Thailand, Kenya). Hence, the overall TI performance is relatively poor in the BRI countries.

When using IQ as a threshold variable, this comprehensive score exceeded -1.3750 in 62 countries, accounting for approximately 93.94% of the sample. In contrast, there are only four countries with IQ less than -1.3750 . The largest is Vietnam, and the smallest is Senegal. It can be found that there is still a large gap between the BRI countries, but the overall performance is superior to that of TI. The same conclusions can also be found in subgroup three, as only 58 countries cross 0.0211 when treating PD as a threshold variable, accounting for 87.88% of the whole sample.

In the subgroup with HC as a threshold variable, this index was more remarkable than 0.8700 in 12 countries, accounting for nearly 18.19% of the sample. This proportion aligns with the subgrouping results with TI as a threshold variable. A possible illustration is that the Neoclassical School of thought proclaims that economic growth is contingent upon the growth rate of capital, labour, and TI, which change over time. One of the remarkable contributions of the Neoclassical theory is to treat TI as an exogenous variable and consider it the same growth factor as capital and labour. However, as an essential source of economic growth and social development in the era of the knowledge economy, it is commonly recognized that HC plays a crucial in TI advancement. The

most important way is that HC promotes TI by learning knowledge and turning it into national productivity (Wen et al., 2022). Therefore, the former conclusion is reliable.

The corresponding results are presented in Table 8. First, the p -values of AR (2) in all models are more remarkable than 0.10, meaning there is no second-order autocorrelation. Still, the p -values of the Hansen test prove the reliability of the constructed IV. In addition, the regression coefficients of NRD under the same mechanism variables are heterogeneous; simultaneously, the estimated coefficients of NRD are also quietly different under different mechanism variables in terms of absolute magnitude and saliency. More specifically, when $TI \leq 9.3428$, NRD has an inhibitory effect on GD, and the restricting effect turns into the promoting effect with further TI advancement in the BRI countries (i.e., when TI exceeds the estimated threshold value of 9.3428). The same conclusions can be found when treating PD and HC as the threshold variables. The resource blessing will be triggered only when PD and HC surpass the threshold of 0.0211 and 0.8700, respectively. The absolute value of NRD in column (2) of Table 7 becomes smaller when IQ surpasses the threshold. In other words, the restricting effect of NRD on GD diminishes significantly after IQ exceeds the threshold value of -1.3750 .

5.3. Non-linear nexus discussion

This study also considers the possible transmission mechanisms between NRD and GD from an international trade perspective. Importantly, we consider two dimensions: trade diversification and digital trade.

Trade diversification represents providing heterogeneous and diversified services and products instead of specialized or concentrated ones. This terminology means variations in the make-up of traded products instead of solely trading volume. In addition, trade diversification also diversifies job opportunities in partner economies, broadens market access, and explores potential businesses for networking with potential customers (Ali et al., 2022). Therefore, trade diversification has a solid potential to power economic advancement and protect the environment because it offers economic structure by providing specialized services. Another possible rationale is that import and export diversification potentially creates technical spillovers. For example, exporting green technologies is expected to boost technical progress in the partner countries, lowering emissions. This study also argues that trade diversification helps solve NRD issues and thus contributes to GD. The stylized fact is that resource-dependent nations may have a single trade pattern. As a result, as these economies rely heavily on a single good for exports, unexpected episodes of economic uncertainty could trigger volatility in resource prices and inhibit economic performance. Thanks to the mechanism of trade development, resource-endowed countries enlarge their trade portfolio, diversify their goods and services, and become globally competitive in the international platform (Hsu et al., 2023). Thus, trade-related exposures can be eased by diversifying and augmenting earnings from exported goods.

Given these considerations, it is noteworthy to assess how NRD can influence GD under the constraint of trade diversification. Specifically, this study extracts the trade diversification index from the UNCTAD. Then, we utilize the partially linear functional-coefficient model⁸ to check the complex nexus between NRD, GD, and trade diversification. Overall, this technique allows for flexible modelling of relationships between variables by accommodating both linear and non-linear functional forms. This flexibility enables the model to capture various relationships, including linear, non-linear, and time-varying effects, without imposing strict parametric assumptions. As mapped in Fig. 5, a non-linear time-varying nexus between NRD and GD is captured when

Table 6
Results of threshold values and the corresponding confidence interval.

95% confidence interval					
Threshold variable	Wald statistic	p-value	Threshold	Lower	Upper
lnTI	103.0257	0.000	9.3428	3.1407	11.5068
lnIQ	235.1668	0.000	-1.3750	-1.8202	-0.0875
lnPD	152.1374	0.000	2.8560	1.7431	5.9787
lnHC	591.9215	0.000	0.8700	0.4761	1.2956

⁸ See Du et al., 2020 for more details regarding model setup and estimation procedures.

Table 7

Grouping classification based on the dynamic panel threshold model in 2019.

	$q_{it} \leq \kappa$	Obs.	$q_{it} > \kappa$	Obs.
InTI (Subgroup 1)	Year = 2005 Lesotho, Indonesia, Dominican Republic, Thailand, El, Salvador, Nepal, Bahrain, Philippines, Tajikistan, Cuba, Gambia, Gabon, Namibia, Bolivia, Panama, Sudan, Egypt, Luxembourg, Senegal, Moldova, Kazakhstan, Cyprus, Sri Lanka, Azerbaijan, Uruguay, Iran, Armenia, Kenya, Bangladesh, Jordan, Morocco, Comoros, Belarus, New Zealand, Bulgaria, Pakistan, Malaysia, Chile, Croatia, Iraq, Angola, Hungary, Portugal, Niger, Czech Republic, Singapore, Madagascar, Dominica, Austria, Fiji, Greece, Israel Year = 2019 Kenya, Thailand, Egypt, Madagascar, Croatia, Seychelle, Ukraine, Fiji, Niger, Gambia, Belarus, Nepal, Luxembourg, Saudi Ara, Moldova, Bahrain, Poland, Senegal, Armenia, Hungary, Azerbaijan, Uzbekistan, Cuba, Chile, Bangladesh, Kazakhstan, Sudan, Sierra Leone, Japan, Burundi, Jordan, Bolivia, Czech Republic, Morocco, Indonesia, Malaysia, Iraq, China, Comoros, Angola, Vietnam Greece	52	Burundi, Saudi Ara, Seychelle, Türkiye, Poland, Albania, India, Sierra Leone, Italy, Vietnam, Ukraine, Japan, China, Uzbekistan	14
InIQ (Subgroup 2)	Year = 2005 Sudan, Indonesia, Belarus, Tajikistan, Cyprus, New Zealand, Cuba, Bangladesh, Philippines, Azerbaijan, Pakistan, Kazakhstan, Egypt, Gambia, Kenya, Thailand, China, Bolivia, Bahrain, Gabon, Moldova, Nepal, Dominican Republic, Morocco, Armenia, El Salvador, Angola, Comoros, Sri Lanka Year = 2019 Senegal; Seychelle; Thailand; Chile	26	Portugal, Austria, Namibia, Iran, Dominican Republic, Panama, Dominica, New Zealand, Bulgaria, Lesotho, Singapore, El Salvador, Sri Lanka, Tajikistan, Pakistan, Philippines, Albania, Gabon, Israel, Turkey, Italy, India, Uruguay, Cyprus Lesotho, Madagascar, Senegal, India, Panama, Jordan, Türkiye, Namibia, Bulgaria, Croatia, Malaysia, Poland, Italy, Uruguay, Greece, Czech Republic, Israel, Hungary, Japan, Portugal, Sierra Leone, Chile, Burundi, Vietnam, Uzbekistan, Singapore, Iraq, Ukraine, Luxembourg, Austria, Albania, Seychelle, Niger, Saudi Ara, Iran, Dominica, Fiji	40
InPD (Subgroup 3)	Year = 2005 Namibia, Bahrain, Iran, Gabon, Kazakhstan, Bolivia, Niger, Angola, Philippines, Sudan, Fiji Year = 2019 Namibia, Bahrain, Iran, Kazakhstan, Gabon, Bolivia, Niger, Angola	11	Saudi Ara, Madagascar, Malaysia, Ukraine, Burundi, Belarus, New Zealand, Croatia, Azerbaijan, Gambia, Bangladesh, Kazakhstan Niger, Lesotho, Cyprus, Sierra Leone, Japan, Fiji, Luxembourg, Kenya, Tajikistan, Morocco, Egypt, Albania, Sudan, Angola, Armenia, Comoros, India, Jordan, Poland, Nepal, Bolivia, Moldova, Greece, Czech Republic, Indonesia, Sri Lanka, Israel, Pakistan, Dominica, Uzbekistan, Philippines, Iran, China, Panama, Uruguay, Gabon, Bulgaria, Italy, Iraq, Hungary, Austria, Turkey, Portugal, Bahrain, Cuba, El Salvador, Dominican Republic, Singapore, Namibia, Vietnam	62
InHC (Subgroup 4)	Year = 2005 Azerbaijan, Senegal, Sudan, Indonesia, Cuba, Nepal, Gambia, Moldova, Bangladesh, Niger, Cyprus, India, El Salvador, Thailand, Namibia, Kenya, Morocco, Türkiye, Poland, Dominican Republic, Comoros, Lesotho, Panama, Gabon Year = 2019 Azerbaijan, Sudan, Senegal, Lesotho, Indonesia, Niger, Cyprus, Moldova, Gambia, Cuba, Nepal, Bangladesh, India, Morocco, Namibia, El Salvador, Kenya, Thailand	24	Uruguay, Chile, Seychelle, Uzbekistan, Cyprus, Comoros, Panama, Nepal, Belarus, Tajikistan, Madagascar, Egypt, Senegal, Iraq, Kenya, Jordan, Lesotho, Thailand, Morocco, Bulgaria, Cuba, Croatia, Malaysia, Greece, Sierra Leone, Türkiye, Austria, Moldova, Azerbaijan, Armenia, Albania, Hungary, Portugal, Vietnam, Gambia, Poland, Czech Republic, Dominica, China, New Zealand, Luxembourg, Saudi Ara, Dominican Republic, Italy, Pakistan, Ukraine, El Salvador, Sri Lanka, Israel, Indonesia, Burundi, Japan, India, Bangladesh, Singapore Philippines, Fiji, Uruguay, Sudan, Seychelle, Chile, Uzbekistan, Comoros, Belarus, Nepal, Cyprus, Panama, Bulgaria, Madagascar, Tajikistan, Egypt, Lesotho, Iraq, Croatia, Morocco, Greece, Senegal, Thailand, Kenya, Moldova, Cuba, Sierra Leone, Malaysia, Armenia, Albania, Hungary, Austria, Türkiye, Portugal, Jordan, Azerbaijan, Vietnam, Poland, Czech Republic, Dominica, China, Gambia, Italy, Saudi Ara, New Zealand, Dominican Republic, Luxembourg, Ukraine, Pakistan, El Salvador, Japan, Sri, Lanka, Burundi, Indonesia, Israel, India, Bangladesh, Singapore	55
		8	China, Madagascar, Uruguay, Egypt, Bolivia, Jordan, Singapore, Pakistan, Sierra Leone, Malaysia, Angola, Greece, Portugal, Albania, Belarus, Chile, Italy, Sri Lanka, Iran, Iraq, Vietnam, Bulgaria, Luxembourg, Croatia, Burundi, Armenia, Hungary, Philippines, Tajikistan, Austria, Fiji, Seychelles, Kazakhstan, Dominica, Israel, Japan, New Zealand, Bahrain, Saudi Ara, Ukraine, Czech Republic, Uzbekistan	42
		18	Poland, Türkiye, Comoros, Panama, China, Egypt, Dominican Republic, Uruguay, Madagascar, Sri Lanka, Gabon, Pakistan, Jordan, Albania, Belarus, Bolivia, Sierra Leone, Tajikistan, Malaysia, Angola, Kazakhstan, Greece, Armenia, Chile, Burundi, Italy, Iraq, Bulgaria, Vietnam, Iran, Austria, Hungary, Seychelle, Philippines, Fiji, Bahrain, Portugal, Japan, Dominica, Croatia, Luxembourg, New Zealand, Czech Republic, Saudi Ara, Uzbekistan, Ukraine, Israel, Singapore	48

Notes: q_{it} regulates the specific threshold, including TI, IQ, PD, and HC; κ represents the particular threshold value under each threshold variable.

Table 8
Regression coefficients of DPT mode.

Threshold variable	(1) TI	(2) IQ	(3) PD	(4) HC
$\ln GD_{i,t-1}$	0.6428 ^c (0.007)	0.5448 ^c (0.005)	0.5794 ^c (0.003)	0.5382 ^c (0.004)
$\ln NRD \cdot I(q_{it} < \kappa)$	-0.0019 ^c (0.000)	-0.0061 ^c (0.002)	-0.0020 ^c (0.000)	-0.0013 ^c (0.002)
$\ln NRD \cdot I(q_{it} \geq \kappa)$	0.0041 ^c (0.001)	-0.0025 ^c (0.000)	0.0013 ^c (0.000)	0.0033 ^b (0.001)
Interference variables	✓	✓	✓	✓
_cons	0.6268 ^c (0.077)	0.7950 ^c (0.031)	0.6922 ^c (0.106)	1.2322 ^c (0.101)
Obs.	924	924	924	924
AR (1)	-1.88 [p-value = 0.061]	-1.79 [p-value = 0.073]	-1.89 [p-value = 0.059]	-1.83 [p-value = 0.067]
AR (2)	1.32 [p-value = 0.187]	1.29 [p-value = 0.196]	1.34 [p-value = 0.181]	1.26 [p-value = 0.208]
Hansen test	53.97 [p-value = 0.944]	54.87 [p-value = 0.934]	58.53 [p-value = 0.874]	59.43 [p-value = 0.855]

Notes: Figures reported in(.) represent standard errors.

q_{it} regulates the specific threshold, including TI, IQ, PD, and HC; κ represents the threshold value under each threshold variable; $I(\bullet)$ is the indicator function.

p < 0.10.

p < 0.50.

p < 0.01.

considering trade diversification. The estimation results demonstrate that NRD harms GD when trade diversification is below 4.871. On the contrary, when trade diversification exceeds the above threshold, the associated adverse effect turns positive. Overall, when the relevant threshold is exceeded, although the relevant estimates are insignificant, this underscores the pivotal role in helping to remedy the adverse impact of NRD on GD to some extent. In other words, trade activities can be recognized as an alternative that enables resource-based nations to lessen reliance on resources and stimulate economic advancement. Still, trade diversification also helps deploy low-carbon technologies, sustaining GD (Zafar et al., 2022) (see Fig. 6).

The second channel is to investigate the NRD-GD conditional on digital trade. Digital trade creates a revolutionary footprint throughout economic sectors by boosting efficiency, customer engagement, and data governance. The WTO declared that digital innovations also tremendously reduced information asymmetries by lowering information retrieval costs. At the same time, the advent of new markets, escorted by digitization, has also shaped global trade patterns, particularly for developing nations. The direct illustration is that digitalization streamlines trade processes by digitizing and automating documentation, customs procedures, and logistics operations. Electronic documentation, such as electronic bills of lading and digital certificates of origin, reduces paperwork, accelerates clearance times, and lowers trade transaction costs. In addition, digital platforms and portals facilitate online trade transactions, payments, and communication between traders, customs authorities, and other stakeholders. Therefore, this study further performs the partially linear functional-coefficient model by considering digital trade, where digital trade is proxied by the sum of ICT-related import and export volumes (i.e., % of gross GDP). As illustrated in Fig. 5, the “resilience” of digital trade on the NRD-GD relationship is more pronounced than that of traditional trade activities because NRD significantly boosts GD when digital trade exceeds 1.632. This finding highlights the critical role of BRICS in helping resource-based economies escape the so-called resource curse dilemma.

5.4. Heterogeneity analysis in the BRI countries

We further validate heterogeneities among the selected BRI countries based on two perspectives: environmental regulation stringency (ERS) and NRD ranking (NRDR). We first check the distribution characteristics of NRD in different groups, as depicted in Fig. 5. We find that GD performance in the high-level ERS group is overall higher than that of the low-level ERS group. Still, the kernel density estimation results also show that the overall GD performance in countries with high-level NRDR is superior to countries with low-level ones. Based on the findings, it is reasonable to conclude that it is hard for countries with low-level ERS and resource-based cities to realize green transformation.

First, although the OECD statistical database has provided an environmental regulation stringency index, the utilization of this dataset will cause too much sample information to be lost. Following Zhao et al. (2022), a comprehensive index is calculated to measure country-level ERS based on three indicators: CEs, nitrous oxide emissions, and methane emissions. The data are collected from the *World Bank database*. We first calculate the emission intensity of each pollutant by using $EI_{i,t} = \frac{P_{i,t}}{IO_{i,t}} / \sum_{i=1}^{66} \frac{P_{i,t}}{IO_{i,t}}$, where $EI_{i,t}$ denotes the emission intensity of the pollutant in country i in year t . $IO_{i,t}$ represents the gross industrial added value (2010 US\$). A comprehensive score is then determined to measure

country-level ERS by adopting $1 / \left[\frac{1}{3} * (EI_{1,it} + EI_{2,it} + EI_{3,it}) \right]$. The higher the ERS score, the stricter the environmental control. Subsequently, the whole sample is divided into two subgroups by judging whether the calculated ERS score of one country is greater than the sample average. Columns (1) & (2) of Table 9 display that NRD has a significant promoting effect on GD in countries with high-level ERS; instead, NRD in countries with low ERS levels tends to worsen GD. ER's effect on pollution emissions is apparent. That is why countries worldwide emphasize establishing the market-based ER system. For example, motivated by the EU carbon trading market, China has established a carbon trading market since 2013, and the fruitful majority of findings have demonstrated the effectiveness of China's carbon trading market in reducing pollution emissions and improving carbon efficiency (Tao et al. (2022); Tang et al., 2020). Hence, a well-designed ER could help economies achieve a “win-win” between energy conservation and pollution mitigation. Empirical findings from this paper also prove that countries with stringent ER can bring resource blessings. The possible illustration is that market participants must adjust their production model towards a sustainable one under the designed ER system; otherwise, they will be phased out of the market or even penalized (i.e., environmental tax). Thus, that country's overall production and energy utilization efficiency will gradually improve.

The sample is divided into two subgroups according to the average NRD following the same classification standards. If $NRD \geq$ sample average NRD, then the corresponding country is assigned to 1; 0 otherwise. Results from columns (3) & (4) of Table 8 imply that the restricting effect of NRD is more evident compared to countries with a relatively low NRD level. The above results show that the green development curse hypothesis only exists in resource-based countries but not non-resource-based countries. Non-resource-based countries have substantially progressed in upgrading industrial structures and advancing TI (Li & Tang, 2017). As a result, the absence of the green development curse hypothesis in non-resource-based countries is credible.

6. Concluding remarks and policy implications

Motivated by the resource curse hypothesis, this paper proposes the green development curse hypothesis. It explores NRD's effect on GD based on the balanced panel data from the selected BRI countries from 2005 to 2019. Our paper is conducted based on the IV-estimation strategy to avoid the so-called possible endogeneity issue, yielding more accurate and reliable results. Based on the research objective, we

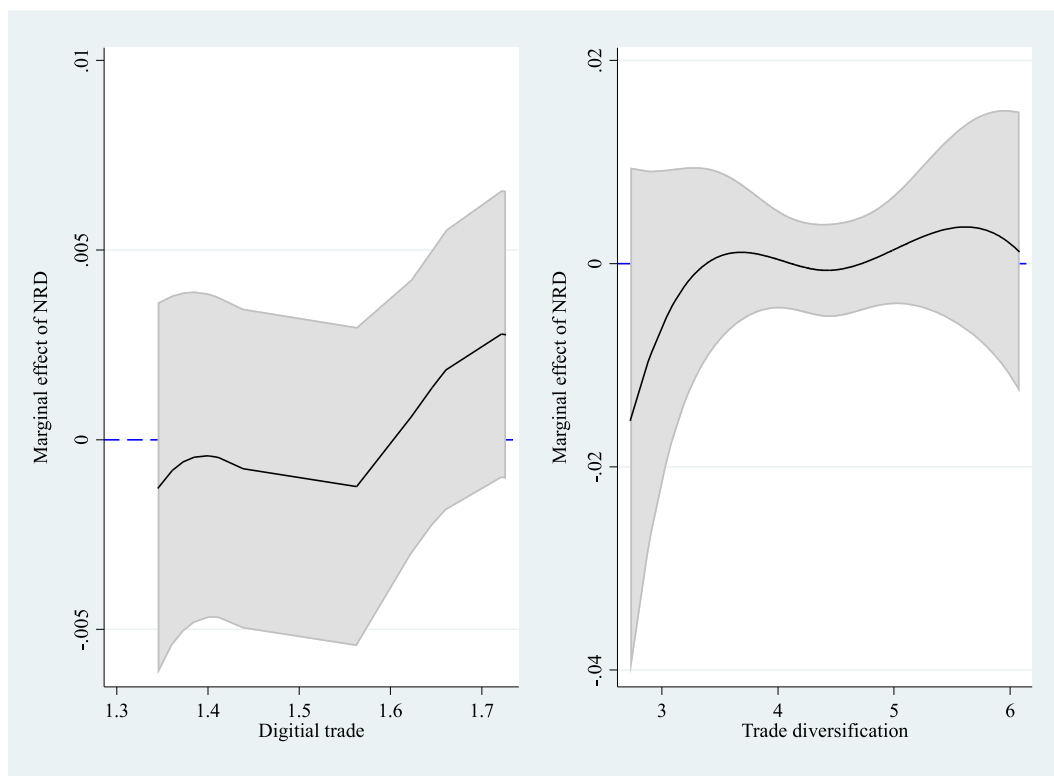


Fig. 5. Functional coefficient maps. Notes: The X-axis represents the regime indicators, including digital trade and trade diversification; the Y-axis denotes the marginal implications of natural resource dependence. The gray portions represent 95% confidence intervals in each plot. The solid black line indicates the estimated parameters.

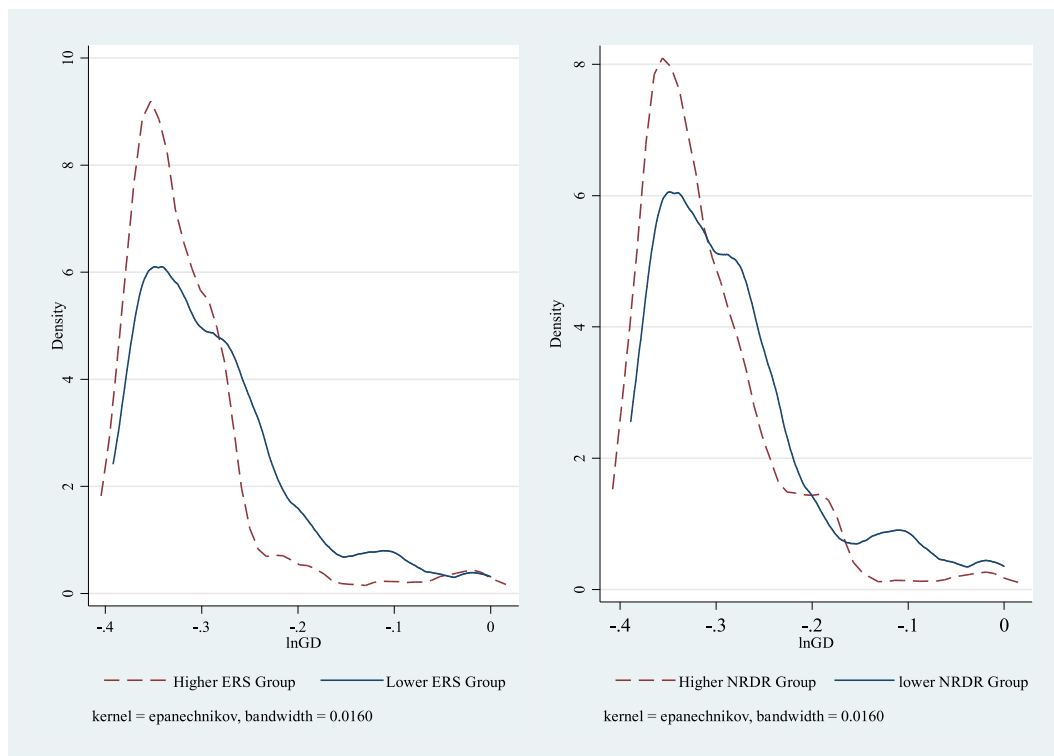


Fig. 6. Kernel density estimation for LNRD in different groups. Notes: The X-axis represents the sample green development values range, and the Y-axis represents the probability density function estimate.

Table 9
Heterogeneity analysis results.

	(1)	(2)	(3)	(4)
	ERD group		NRDR group	
	Is it high-level ERS?		Is it a resource-based country?	
	Yes	No	Yes	No
lnNRD	0.0262 ^a (0.014)	−0.0673 ^c (0.016)	−0.0541 ^c (0.012)	0.0050 (0.032)
KP rk LM statistic	12.004 (0.000)	26.811 (0.000)	28.599 (0.000)	13.939 (0.000)
Control variables	Yes	Yes	Yes	Yes
Country fixed effect	✓	✓	✓	✓
Year fixed effect	✓	✓	✓	✓
Obs.	157	833	255	735
1st stage regression				
Dependent variable: lnNRD				
ln(LA * REERI)	−1.8784 ^c (0.561)	0.5979 ^c (0.114)	0.8414 ^c (0.155)	−0.3922 ^c (0.107)
Control variables	✓	✓	✓	✓
F statistics	11.198	27.519	29.553	13.486

Notes: Figures reported in(.)represent standard errors.
p < 0.10.
p < 0.50.
p < 0.01.

explore the underlying channels through which NRD affects GD from four perspectives: TI, IQ, PD, and HC. Subsequently, a novelty dynamic panel threshold model incorporating a two-step SYS-GMM approach and addressing possible endogeneity problems is established to validate the nonlinear relationship between NRD and GD under TI, IQ, PD, and HC. Additionally, the whole sample is categorized into subgroups based on ERS and NRDR to validate the heterogeneous effects. The main findings are summarised as follows. First, the green development curse hypothesis is identified in the BRI countries, regardless of which methods are used to check the benchmark regression results. Second, the IV-based three-step mediation effect model results show that NRD could depress green development by weakening innovative capability, distributing institutional quality, and crowding out advanced HC. Therefore, TI, IQ, and HC mediate NRD and GD. Further analysis from a dynamic panel threshold model verifies the occurrence of a nonlinear relationship between NRD and GD under four mechanism variables: TI, IQ, PD, and HC. Besides, we also find that the inhibitory effect of NRD on GD can turn into a promoting effect when TI, PD, and HC exceed the corresponding estimated threshold values. In the meantime, the restricting impact of NRD on GD can be significantly weakened after IQ surpasses the threshold value, but the green development curse still exists. This outcome may lie in the poor IQ in the BRI countries. Third, heterogeneous analysis reveals that the green development hypothesis only works in countries with high-level NRS and resource-based countries.

The derived findings of this study yield several policy implications. First, although countries worldwide aim to advance towards sustainable energy targets, the current pace of progress is insufficient to achieve Goal 7 by 2030.⁹ The dramatic improvement of energy efficiency needs to accelerate to reach the climate goal of mitigating GHGs. However, hundreds of millions still lack access to natural gas electricity and slow progress towards clean solutions. In other words, considerable disparities in access to modern sustainable energy persist, leaving the most vulnerable even further behind. Still, the COVID-19 pandemic has weakened progress or advances already made. Although abundant NRs play a crucial role in the earlier stages of economic development, more emphasis should be placed on those resource-based regions in the process of low-carbon transition progress by formulating strategic plans.

⁹ See <https://unstats.un.org/sdgs/report/2022/The-Sustainable-Development-Goals-Report-2022.pdf>.

Our empirical findings have demonstrated the existence of the green development curse hypothesis in the BRI countries. That is, unsustainable depletion and utilization of NRs undoubtedly hinder GD.

Second, fortunately, the green development curse can be alleviated under certain conditions by strengthening technological innovation, optimizing institutional structures, reducing PD, and advancing HC. Note that the mechanism analysis results designate that TI performance and IQ level are not high-quality. Still, both current TI and IQ levels are not conducive to sustaining GD in the BRI countries; simultaneously, the findings from a dynamic panel threshold model also verify this crucial point. Resource blessings will be triggered only when PD and HC surpass the estimated threshold values. Therefore, it is recommended that the BRI countries, especially the resource-based countries, invest more in TI to strengthen innovative capability, which will help improve overall energy efficiency and stimulate sustainable economic growth. At the same time, they also suggest designing a reasonable institutional structure that is better for enjoying the promoting effect of IQ on GD. In addition, country-level incentive policies should be formulated and introduced to attract professional talents to participate in local social development and economic construction. However, counties should consider the population over-agglomeration effect as it may adversely affect GD.

Third, digital trade has a strong “resilience” compared to traditional trade and can correct the resource curse of the BRICS countries. Hence, the BRI countries are advised to implement policies to promote digitalization across sectors, including natural resource-based industries, by investing in digital infrastructure, broadband connectivity, and digital skills development. Encouraging innovation and entrepreneurship in digital technologies can help diversify economies and reduce reliance on resource-intensive sectors. Moreover, cutting off the transmission paths for the green development curse is also necessary. Based on this, a desirable policy package and a well-designed ER system should be introduced. It is strongly recommended that countries should consider carbon reduction targets when introducing relevant environmental policies. It is noteworthy that overly stringent ER should be avoided because it can cause negative spatial spillovers that could reinforce the green development curse in neighboring areas. This is because enterprises with high-polluting emissions and low innovative capability will move into adjacent areas, thereby increasing pollution emissions.

CRedit authorship contribution statement

Hanghang Dong: Writing – review & editing, Writing – original draft, Resources, Methodology, Formal analysis. **Miaomiao Tao:** Writing – review & editing, Writing – original draft, Validation, Formal analysis, Data curation. **Le Wen:** Writing – review & editing, Writing – original draft, Resources. **Stephen Poletti:** Writing – review & editing, Writing – original draft, Conceptualization. **Mingyue Selena Sheng:** Writing – review & editing, Writing – original draft, Methodology.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.envres.2024.119108>.

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