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# Can the Belt and Road Initiative Empower Sustainable Development in Developing Countries?

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## ABSTRACT

This article delves into the significant positive impact of the Belt and Road Initiative (BRI) on the sustainable development of developing countries, particularly those with lower levels of industrialization and higher sustainable development performance. The study, utilizing the super-efficiency Slacks-Based Measure (SBM) model, evaluates Green Total Factor Productivity (GTFP) as a sustainable development indicator and employs the Difference in Differences (DID) model to assess the BRI's influence.

Findings indicate that the BRI notably benefits countries with lower industrialization levels, developed financial services, high dependence on foreign investment, and lower energy consumption. The research underscores the importance of understanding the BRI comprehensively for policymakers, investors, and the developing countries themselves.

For policymakers, these insights aid in formulating more targeted policies by understanding the BRI's global influence. Investors gain valuable insights into investment returns and risks along the Belt and Road route. Academically, the study advances theoretical understanding of the interplay between the BRI, international investment, and sustainable development, enriching economic literature on developing countries and suggesting avenues for future research.

## ملخص

يتناول هذا البحث الأثر الإيجابي الكبير لمبادرة الحزام والطريق (BRI) على التنمية المستدامة للبلدان النامية، لا سيما تلك التي تكون مستويات التصنيع فيها منخفضة وأداء التنمية المستدامة عاليا. تعتمد الدراسة على القياس القائم على التراخي لزيادة الكفاءة (SBM) وتقيم مجموع عوامل الإنتاجية الخضراء

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(GTFP) كمؤشر من مؤشرات التنمية المستدامة، كما تستخدم أسلوب الاختلاف في الاختلافات (DID) لتقييم أثر مبادرة الحزام والطريق.

تشير النتائج إلى أن مبادرة الحزام والطريق تعود بالفائدة بشكل ملحوظ على البلدان ذات مستويات التصنيع المنخفضة، والخدمات المالية المتقدمة، والاعتماد الكبير على الاستثمار الأجنبي، وانخفاض استهلاك الطاقة. يؤكد البحث على أهمية فهم صانعي السياسات والمستثمرين والبلدان النامية لمبادرة الحزام والطريق بشكل شامل.

وتساعد هذه الأفكار صانعي السياسات على صياغة سياسات أكثر استهدافًا من خلال فهم التأثير العالمي لمبادرة الحزام والطريق. يوفر البحث كذلك رؤى قيمة للمستثمرون حول عوائد الاستثمار والمخاطر المتعلقة بمبادرة الحزام والطريق. من الناحية الأكاديمية، تعمل الدراسة على تعزيز الإطار النظري للعلاقة بين مبادرة الحزام والطريق والاستثمار الدولي والتنمية المستدامة، وإثراء الأدبيات الاقتصادية حول البلدان النامية واقتراح سبل للبحث في المستقبل.

## RESUME

Cet article examine l'impact positif significatif de l'initiative "la Ceinture et la Route" (BRI) sur le développement durable des pays en développement, en particulier ceux dont les niveaux d'industrialisation sont plus faibles et dont les performances en matière de développement durable sont plus élevées. L'étude, qui utilise le modèle de mesure de la super-efficacité Slacks-Based Measure (SBM), évalue la productivité totale des facteurs verts (GTFP) en tant qu'indicateur de développement durable et utilise le modèle de la différence dans les différences (DID) pour évaluer l'influence de l'initiative "la Ceinture et la Route".

Les résultats indiquent que la BRI bénéficie notamment aux pays ayant un niveau d'industrialisation plus faible, des services financiers développés, une forte dépendance à l'égard des investissements étrangers et une consommation d'énergie plus faible. L'étude souligne l'importance d'une compréhension globale de la BRI pour les décideurs politiques, les investisseurs et les pays en développement eux-mêmes.

Pour les décideurs politiques, ces informations aident à formuler des politiques plus ciblées en comprenant l'influence mondiale de la BRI. Les investisseurs obtiennent des informations précieuses sur les rendements et les risques des investissements le long de la Ceinture et de la Route. Sur le plan académique, l'étude fait progresser la compréhension théorique de l'interaction entre la BRI, l'investissement international et le développement durable, enrichissant la littérature économique sur les pays en développement et suggérant des pistes de recherche pour l'avenir.

**Keywords**：Super Slacks-Based Measure model, Difference in Differences, Belt and Road Initiative, Sustainable Development

## 1.Introduction

### 1.1.Research background

Since the Belt and Road Initiative (BRI) was proposed by China in 2013, it has received widespread attention from the international community. The BRI aims to promote regional economic integration and achieve common prosperity and development by strengthening the connectivity among countries along the route. However, current academic research on whether the BRI can truly enhance the sustainable development capacity of developing countries remains at the qualitative analysis level, lacking rigorous quantitative research. Therefore, this study aims to quantitatively assess the BRI's impact on developing countries' sustainable development. The difficulty of the research lies in how to select appropriate indices to assess a country's sustainability performance and evaluate the effectiveness of the policy. To address this issue, this paper adopts the super-efficiency Slacks-Based Measure (SBM) model to measure Green Total Factor Productivity (GTFP) to assess developing countries' sustainable development. At the same time, the Difference-in-Differences (DID) model is used to evaluate the influence of the BRI on the sustainable development of developing countries. The research results show that the BRI can enhance the sustainable development capacity of developing countries. Specifically, developing countries with lower income, higher sustainable development performance, lower innovation performance, lower level of industrialization, developed financial services, high dependency on foreign investment, and lower energy consumption have more significant improvements in sustainable development performance under the BRI.

### 1.2. Practical Implications

First, deepening policy decision reference: This study provides scientific evidence for policymakers through quantitative analysis of the influence of the BRI on sustainable development in developing countries. This evidence is particularly valuable for countries with low income, high performance in sustainable development, low performance in innovation, low level of industrialization, developed financial services, high dependence on foreign investment, and low energy consumption. These countries can utilize the findings of this paper as an essential reference for their participation in the BRI, thereby promoting their sustainable development. Second, promoting global sustainable development: This study proves that the BRI can enhance the sustainable development of developing countries, which is of significant importance to global sustainable development. It reveals the positive impact of regional economic integration and interconnection on sustainable development, providing a reference for other regions in the world seeking paths to sustainable development. This highlights the BRI's global influence and demonstrates its essential role in promoting global sustainable development. Third, optimizing the implementation path of the BRI: The research results help relevant countries and organizations better understand and assess the impact of the BRI so as to optimize the implementation strategies of the BRI, making it more effective in promoting the sustainable development of participating countries. This provides all participating countries with scientific decision-making tools, assisting them in making more rational and effective decisions during the implementation process. Fourth, it contributes to enriching related research methods. This paper uses the super-efficiency SBM model and DID model, providing a new research method for related studies of the BRI and also offering a reference for future relevant research. The application of this method not only enriches the research means of the BRI but also provides a new approach and tool for research in other related fields.

### 1.3. Originality

First, the application of quantitative analysis methods: Compared to the existing research on the influence of the BRI on sustainable development, this study adopts a more rigorous and scientific quantitative analysis method. Specifically, this paper used the super-efficiency SBM model and the DID model. Both of these models are widely used quantitative analysis tools in the fields of economics and social sciences. They can effectively control confounding variables, thus providing more objective and accurate assessment results. Second, comprehensive indicator system: In selecting indicators for measuring national sustainable development performance, this study fully considers multiple factors such as economy, society, and the environment. The purpose of doing so is to make the assessment results more representative and universal and to comprehensively reflect a country's actual situation in terms of sustainable development. Third, in-depth exploration of influencing factors: This study reveals the influence of the BRI on the sustainable development performance of diverse categories of nations through rigorous analysis. This result not only helps us better understand the actual effect of the BRI but also provides a targeted reference for policymakers. Fourth, enlightenments of empirical studies: The research results show that the BRI possesses the potential to enhance the sustainable growth of nations in the developing world. This finding provides valuable experience and reference significance to other countries and regions in promoting sustainable development, especially those who are seeking a balance between economic growth and environmental protection. Fifth, provision of policy recommendations: Finally, this research provides strategic guidance for improving sustainable development outcomes within the framework of the BRI for the involved nations. These suggestions aim to foster mutual growth and advancement among the countries along the BRI path and contribute to the global sustainable development goals.

### 1.4. Research the contribution and shortcomings of this paper

The topic is highly relevant in the context of current global economic and developmental challenges. The BRI is a significant international project, and its impact on sustainable development is a critical area of study. The study takes a comprehensive approach, examining the BRI's impact on sustainable development, referencing the United Nations' Sustainable Development Goals (SDGs). The paper fills a gap in the existing literature by providing a quantitative analysis where previous research may have been predominantly qualitative. This approach can offer more empirical insights and data-driven conclusions. Utilizing models like the super-efficiency SBM and the DID model shows a commitment to robust and sophisticated analytical methods. The paper acknowledges the varied impacts of the BRI on different countries, considering factors like income levels, industrialization, and energy consumption. This nuanced approach is crucial for understanding complex international initiatives like the BRI.

While the quantitative focus is a strength, the lack of qualitative analysis might overlook the nuanced socio-political and cultural impacts of the BRI, which are harder to quantify but equally important. The study primarily focuses on how the BRI can enhance sustainable development, and there might be an inadvertent underemphasis on potential negative impacts, such as environmental degradation or debt sustainability issues. The paper may not fully explore all relevant SDGs in relation to the BRI.

## 2. Literature review

### 2.1. Quantitative indicators for evaluating sustainable development – GTFP

Beginning in 1960, a series of environmental crises and resource challenges, including global warming, land desertification, resource scarcity, and environmental degradation, have emerged as pressing issues necessitating immediate attention (Chiu & Lee, 2020; Hao et al., 2018; Wang & Lee, 2022; Wen et al., 2022). In the face of evolving climate conditions and heightened ecological risks, alongside pursuing sustainable development objectives, numerous nations have initiated the advancement of green economies. This approach entails a balanced integration of economic activities, resource management, and ecological considerations. Consequently, a pivotal inquiry emerges: Which metrics evaluate a nation's effectiveness in addressing environmental issues, enhancing environmental performance, and maintaining sustainable economic growth?

Numerous economists have conducted intensive research in this area. The earliest research results were based on the traditional So low and endogenous growth models. This theory suggests that a sustainable economy depends only on technological progress, usually measured by an increase in total factor productivity (TFP). However, the related measurement methods must consider the social benefits of resources, the environment, and other factors(Chen & Golley, 2014a; Tian & Lin, 2017). The manifestation of this deficiency becomes apparent in situations where energy and environmental considerations emerge as substantial limitations on economic expansion. In such cases, a fraction of the resources initially allocated for production needs to be redirected towards environmental management endeavors. This circumstance can potentially result in the issuance of erroneous policy recommendations (Liu et al., 2020a).

In the subsequent period, the Asian Productivity Organization (APO) pioneered the introduction of the concept known as 'GTFP', which emerged in the 1990s and was grounded in the foundational concept of TFP. This novel introduction garnered significant scholarly interest. Since then, researchers have extensively studied the measurement of green TFP and assessed whether the sustainability of the economy could be assessed by measuring green TFP growth. For example, recent studies have considered energy constraints and environmental performance and thus examined GTFP(Gao et al.,2021; Xia & Xu, 2020; Yan et al., 2020; J., 2021).

Within these discourses, GTFP is regarded as a more effective measure for gauging sustainable economic development (Feng et al., 2018; Liu et al., 2020b; Yan et al., 2020). For instance, Feng et al. 2018 commented that, in the early traditional TFP indicator based studies, resource conservation and emissions reduction should be two main connotations of sustainability and green development, the neglect of them could mislead the true sustainability of an economy (Chen & Golley, 2014). The advantage of GTFP is that it extends the traditional TFP framework by incorporating environmental factors and resource inputs into its analysis. This approach provides a more comprehensive and environmentally sensitive measure of productivity. Consequently, drawing upon prior research, this study also employs the GTFP indicator to assess the economic sustainability of the 15 countries along the BRI.

**2.2. Super SBM model**

Reflecting upon the discussions above, it becomes evident that resource and environmental limitations are imperative in evaluating GTFP. Nonetheless, numerous initial studies approached this by treating undesirable outputs as inputs, as observed in works (Ramanathan,2005; Reinhard & Thijssen, 2000) or employed data transformation techniques for such outputs (Scheel, 2001; Seiford & Zhu, 2002). These methods, however, might conflict with the actualities of the production process, potentially leading to inaccurate appraisals of green productivity growth. An alternative method involves the utilization of the Directional Distance Function (DDF), which incorporates a weak disposability premise for non-desired outputs.

For instance, in accordance with the DDF methodology as proposed (Gao et al., 2021), an investigation was conducted into China's provincial total factor productivity while taking carbon emissions into account. Nevertheless, it is worth noting that the DDF approach tacitly presupposes uniform variations in desirable and undesirable output ratios, a premise not congruent with real-world observations (Chen & Golley, 2014b). Many recent studies have thus turned their attention to using the relaxed,

nonradial, and nonoriented SBM model proposed by Tone(Tone, 2001). Based on this, the super SBM model was developed by Tone(Tone, 2002)by combining the advantages of super-efficient Data Envelopment Analysis (DEA) and SBM models. Subsequently, the Super SBM model has developed significantly and emerged as the preeminent and extensively adopted instrument for evaluating green productivity growth. Illustrative instances of its utilization include studies (Guo & Yuan, 2020a; Liu et al., 2021; Wuand Zhang, 2020; Yu et al., 2019).
In this study, the assessment of GTFP is conducted through the application of the Super SBM model with undesirable outputs as introduced (Tone, 2002). This methodology offers three distinct advantages:

(1) Reducing undesirable output incurs a cost, aligning with the inherent aspects of the production process.

(2) In contrast to conventional DEA methodologies that disregard input or output slack, resulting in potentially skewed estimations, the Super SBM model incorporates slack variables into the objective function, thereby mitigating radial and directional bias as proposed (Song et al., 2012).

(3) Using the Super-efficient SBM model, multiple effective Decision Making Units (DMUs) can be ranked efficiently (Guo & Yuan, 2020b).3. Empirical model and methodology

### 3.1. SBM model with undesired outputs

We define the object of study as $DMU_s$,which is a collection of decision units. $DMU_s$=(X,Y,Z) ,where X represents the input, Y represents the output, and Z represents the undesired output; X, Y, and Z are all matrices.

$$X = \begin{bmatrix} x_{11} & x_{12} \cdots & x_{1n} \\ x_{21} & x_{22} \cdots & x_{21} \\ \vdots & \ddots & \vdots \\ x_{m1} & x_{m2} \cdots & x_{mn} \end{bmatrix}_{m \times n}$$

$$Y=\begin{bmatrix} y_{11} & y_{12}\cdots & y_{1n} \\ y_{21} & y_{22}\dots & y_{21} \\ \vdots & \ddots & \vdots \\ y_{S_1 1} & y_{S_1 2}\cdots & y_{S_1 n} \end{bmatrix}_{S_1\times n}$$

$$Z=\begin{bmatrix} z_{11} & z_{12}\cdots & z_{1n} \\ z_{21} & z_{22}\dots & z_{21} \\ \vdots & \ddots & \vdots \\ z_{S_2 1} & z_{S_2 2}\cdots & z_{S_2 n} \end{bmatrix}_{S_2\times n}$$

$$X\in R^{m\times n}, Y\in R^{S_1\times n}, X\in R^{S_2\times n}$$

We follow (Tone, 2001) and the set of production possibilities is P.

$$P=\{(x,y,z)|x\geq X\lambda, y\leq Y\lambda, z\geq Z\lambda, \lambda\geq 0\}$$
$$\lambda\in R^{n\times 1}$$

Why is the possible set of production P? Because we will have excess inputs and insufficient outputs in the production process, our efficiency could be better. We name excess inputs, insufficient outputs, and excessive undesired outputs as slack variables $s_x$,$s_y$,$s_z$. Then we can get the following relation:

$$x_0=X\lambda+s_x$$
$$y_0=Y\lambda-s_y$$
$$z_0=Z\lambda+s_b$$
$$s_x\geq 0, s_y\geq 0, s_b\geq 0$$

We can explain our production possibility set P (Equation 4) based on the above formulas. It is worth noting that $x_0$, $y_0$, $z_0$ do not represent an element but a vector. The equation below corresponds to the introduced SBM model (Tone,2001) :

$$min\rho=\frac{1-\frac{1}{m}\sum_{i=1}^{m}\frac{s_{x_i}}{x_{i_0}}}{1+\frac{1}{s_1+s_2}\left(\sum_{j=1}^{s_1}\frac{s_{y_i}}{y_{i_0}}+\sum_{r=1}^{s_2}\frac{s_{b_r}}{z_{r_0}}\right)}$$

$$s.t.\begin{cases} x_0 = X\lambda + s_x \\ y_0 = Y\lambda - s_y \\ z_0 = Z\lambda + s_b \\ \lambda \geq 0, s_x \geq 0, s_y \geq 0, s_b \geq 0 \end{cases}$$

Next, the optimal solution to the system of equations can be found $(\rho^*, s_x^*, s_y^*, s_b^*, \lambda^*)$ When our inputs, outputs, and non-expected outputs are the same as the indicators in Table 1 $\rho^* \Leftrightarrow GTFP$.

**Table1:** Input and output indicators

| Type | Variable | Definition |
|---|---|---|
| Input | Labor force | Workforce(Millions of people) |
| | Capital stock | Total capital investment(Billion dollars) |
| | Energy input | Total energy consumption(Millions of tons) |
| Output | Economic output | GDP(Billion dollars) |
| Undesirable output | Environmental pollution | Carbon dioxide emissions(Millions of tons) |

Now let us go back to Equation4. when the set of possibilities all take the equal sign, then there is no excess input, no deficient output, and too much non-desired output, then the slack variables $s_x$,$s_y$,$s_z$ are all 0, then the state is called effective, and it is at this point $\rho = 1$. More details can be found in (Tone, 2001; Tone & Sahoo., 2003).

### 3.2. Super SBM model with undesired output

In the course of this study, there are several countries with efficiency values of 1. How should we compare the efficiency of these countries? Tone ( Tone,2002) provides a further formula for this problem:

$$min\rho = \frac{1+\frac{1}{m}\sum_{i=1}^{m}\frac{s_{x_i}}{x_{i_0}}}{1-\frac{1}{s_1+s_2}\left(\sum_{j=1}^{s_1}\frac{s_{y_i}}{y_{i_0}}+\sum_{r=1}^{s_2}\frac{s_{b_r}}{z_{r_0}}\right)}$$

$$s.t.\begin{cases} x_0 = X\lambda + s_x \\ y_0 = Y\lambda - s_y \\ z_0 = Z\lambda + s_b \\ 1-\frac{1}{s_1+s_2}\left(\sum_{j=1}^{s_1}\frac{s_{y_i}}{y_{i_0}}+\sum_{r=1}^{s_2}\frac{s_{b_r}}{z_{r_0}}\right) > 0 \\ \lambda \geq 0, s_x \geq 0, s_y \geq 0, s_b \geq 0 \end{cases}$$

Similar to the SBM model above, we can solve the optimal solution. Since this paper is not a separate study of the SBM model and the Super SBM model, we do not focus on explaining the solution to the problem here; scholars who want to know more details can refer to (Tone, 2001, 2002; Zhenhua and Gang.,2013), and the literature listed in the second subsection of section III of this paper.

### 3.3. Difference-in-Differences Model

In recent years, it has become popular in academia to use quasi-natural experiment-based DID models to estimate policy implementation effects(Rothbard et al., 2023; Huang & Chen, 2022; Wang & Jv, 2022; Shen et al., 2023; Feng & Wang, 2021). Such models can effectively mitigate the impact of non-policy factors on estimation results by utilizing two differences. The most critical aspects of estimation using the DID model are the determination of the timing of the policy shock and the selection of the experimental and control groups. To determine the timing of policy shocks, this study chooses 2013 as the time of policy shocks, with the time after 2013 denoted as 1 and the time before 2013 denoted as 0. Regarding the selection of experimental and control groups, implementing the BRI can be regarded as a quasi-natural experiment, and the developing countries that have joined the cooperation of ”One Belt, One Road” can be considered the control group developing countries. In the design of the benchmark model, this paper designs the following model according to the principle of DID model to identify the impacts of BRI on the sustainable development of developing countries.

$$GTFP_{it} = \alpha_0 + \alpha_1(treat_{it} \times time_{it}) + X_{control}\alpha_2 + C_i + \lambda_t + trend_j + \varepsilon_{it}$$

In this context, 'i' represents the country, while 't' signifies the year. GTFP quantifies the specificity, computed using the super-efficient SBM model, where 'treat' is assigned the value 1 for the experimental group and 0 for the control group. 'Time' is a temporal grouping variable, taking on the value 0 for 2005-2013 and 1 for 2013-2019.

$X_{control}$ denotes control variables. Following the references (Cheng et al., 2018; Wu et al., 2020a, b; Yuan et al., 2020), the scale effect is assessed using Gross Domestic Product (GDP), Per Capita Gross Domestic Product (PGDP), and financial support (FS). The technological effect is evaluated through research and development (R&D) investment and foreign direct investment (FDI), as per the mentioned studies. Additionally, the structural effect is measured using industrial structure (INS) and energy consumption structure (ES).

$lambda_t$ denotes time-fixed effects (TFE), while $C_i$ denotes country-level fixed effects that remain constant over time. Considering the potential impact of country-level unobservables that may change over time and affect the sustainable performance of the country, this paper incorporates country-specific time trends (denoted by $yeartrend_j$) to control for changes in these unobservable country-level factors. The $epsilon_{it}$ denotes the random disturbance term. In line with the principles of the DID model, this paper emphasizes the coefficients $\alpha_1$ of the interaction term treat × post.

4. Data description

The data in this article primarily come from the World Bank and the Wind Information Database (WIND). These data sources cover a wide range of fields, providing information for analyzing and interpreting research problems. Before starting data analysis, this research carried out a series of preprocessing and cleaning steps on the initial data to ensure its accuracy and stability. Firstly, to reduce the effects of dimensional differences among different indicators, the initial data were normalized. The paper refers to the research of (Han et al., 2018; He et al., 2019), where normalization was done on the raw data. Normalization is a common data preprocessing method that eliminates the impact of dimensions on the results by converting each indicator to the same scale range, thus giving the different indicators comparability. The processed data is then more convenient for subsequent statistical analysis and modeling.

$$X_{ij} = \frac{X_{ij} - \min(X_{ij})}{\max(X_{ij}) - \min(X_{ij})}$$

After the above preprocessing and cleaning, the comprehensive data were obtained, and missing values were removed. This article obtained a strongly balanced panel data set spanning 15 developing countries(Table2) and the time period from 2006 to 2019. This data set includes 210 observations, covering the relevant index information of various countries during different time periods. These data provide valuable information resources for this article, which is conducive to delving into the inherent laws and characteristics of the research issue. It is worth noting that in the data cleaning process, the paper has always followed the best practice principles in the field of data science, striving to ensure the authenticity, completeness, and reliability of data.

**Table2:** Meaning of serial number

| **Serial number** | **1** | **2** | **3** | **4** | **5** |
|---|---|---|---|---|---|
| Country | Argentina | Austria | Chile | China | Ecuador |
| Serial number | 6 | 7 | 8 | 9 | 10 |
| Country | Indonesia | Malaysia | Morocco | Peru | Philippines |
| Serial number | 11 | 12 | 13 | 14 | 15 |
| Country | Poland | South Africa | Thailand | Turkey | Vietnam |

In conclusion, the data used in the paper are sourced from various authoritative channels and have undergone rigorous preprocessing and cleaning operations, providing a high-quality, strongly balanced panel data set for subsequent research. This data will offer robust support for future studies.

The tabulated presentation of descriptive statistics for the variables can be observed in Table 3:

**Table3:** Descriptive statistics

| Variables | Descriptive | Obs | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|---|---|
| GTFP | Green total factor productivity | 210 | 0.449 | 0.283 | 0.092 | 1.274 |
| TP | Treat×Post | 210 | 0.252 | 0.435 | 0 | 1 |
| ES | Energy use (kg of oil equivalent per capita) | 210 | 1708.727 | 997.633 | 413.21 | 4078.81 |
| FDI | Foreign direct investment, net inflows (% of GDP) | 210 | 2.863 | 2.643 | -7.316 | 17.717 |
| FS | Insurance and financial services (% of commercial service exports) | 196 | 3.334 | 3.022 | 0 | 18.406 |
| INS | Industry (including construction), value added (% of GDP) | 210 | 32.712 | 6.508 | 21.782 | 48.061 |
| PGDP | GDP per capita growth (annual %) | 210 | 3.196 | 3.059 | -6.854 | 13.636 |
| RD | Research and development expenditure (% of GDP) | 138 | 0.893 | 0.791 | 0.055 | 3.172 |

## 5. Empirical findings

### 5.1. Basic regression results

Table 4 presents the outcomes of the primary regression analysis, encompassing four distinct models. Specifically, Models (1) and (3) are conducted without the incorporation of control variables, whereas Models (2) and (4) include them. Models (1) and (2) use the Fixed Effects (FE) model for regression analysis, whereas Models (3) and (4) adopt the High Dimensional Fixed Effects (HDFE) model. This study focuses on the core explanatory variable TP (Trade Surplus) (measuring the DID of the BRI). In all four models, the TP variable is significantly positive, indicating that the BRI has a significant positive impact on the GTFP of developing countries. The FE model is mainly used to eliminate the influence of unobservable heterogeneity, such as considering hard-to-quantify or observe heterogeneity factors like individual countries' natural conditions, geopolitics, culture, and policy environment. Coupled with the R-square results from the FE model, it can be inferred that the explanatory power of the model increases after these potential heterogeneity factors are excluded, i.e., our model predicts GTFP more accurately after these factors are filtered out. From the above results, we can also conclude that it is necessary to include individual and TFE. This is evidenced by the significantly higher R-square in the FE model, which demonstrates that these FE play a significant role in our model. The HDFE model, on the other hand, expands on the FE model by allowing for the consideration of more complex FE. Given the higher explanatory power (R-square) of the HDFE model, it seems that this model could potentially capture the factors affecting GTFP more effectively. Hence, in the subsequent analysis, this study will employ the HDFE model.

In summary, the central independent variable, TP, exhibits a statistically significant favorable influence on the dependent variable, and both the FE model and the HDFE model serve as effective tools for controlling and elucidating this influence. Employing these two models facilitates a more in-depth and comprehensive comprehension of the effects of the BRI on the sustainable development of developing nations.

### 5.2. Heterogeneity Analysis

Table 5 reports the results of the heterogeneity analysis. Models (5) and (6) group the samples according to income, with countries with PGDP higher than the sample mean labeled as high-income countries and those lower than the mean labeled as low-income countries.

**Table4:** Basic regression results

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| | FE | | HDFE | |
| TP | 0.0801** | 0.0685* | 0.0801** | 0.0706* |
| | [2.4099] | [1.7095] | [2.9640] | [1.9156] |
| pgdp | | 0.1099 | | 0.1669 |
| | | [1.1843] | | [1.3202] |
| rd | | 0.2434 | | -0.1535 |
| | | [0.9011] | | [-0.6214] |
| ins | | -0.0958 | | -0.0343 |
| | | [-0.5221] | | [-0.1990] |
| fs | | -0.1702 | | -0.1573 |
| | | [-0.9477] | | [-0.5818] |
| fdi | | -0.1552 | | -0.1595* |
| | | [-1.4550] | | [-1.7889] |
| es | | -0.8412* | | -0.9277* |
| | | [-1.8807] | | [-2.1457] |
| _cons | 0.3413*** | 0.9025*** | 0.3424*** | 1.0287*** |
| | [10.9605] | [3.3231] | [50.1865] | [4.6835] |
| N | 210 | 118 | 210 | 118 |
| r2 | 0.081 | 0.13 | 0.7922 | 0.8423 |
| Time fixed effect | YES | YES | YES | YES |
| Individual fixed effect | YES | YES | YES | YES |

*t* statistics in brackets
$^{*}$ $p < 0.1$, $^{**}$ $p < 0.05$, $^{***}$ $p < 0.01$

The regression coefficient of the core explanatory variable TP in the model (5) is -0.0481. It is insignificant, while in the model (6), the regression coefficient of the core explanatory variable TP is 0.0623, with a significance level of 10%. This suggests that the BRI has a more significant positive impact on the sustainable development of low-income countries than high-income ones. Possible reasons include: First, infrastructure construction: According to relevant reports, connectivity is the cornerstone of interconnectivity and a priority area of BRI construction. The goal is to enhance infrastructure construction, strengthen connectivity in transportation, electricity, communications, etc., and facilitate trade and investment in the region. For many low-income countries, infrastructure is one of the key obstacles to economic growth, and the BRI offers an opportunity to address this issue. Secondly, economic aid and investment: The BRI encourages China and other participating countries to provide economic aid and investment to low-income countries. These funds can be applied in critical areas such as infrastructure construction, education, healthcare, etc., promoting sustainable development in these nations.

Models (7) and (8) group samples based on their sustainable development performance. Countries with a GTFP higher than the sample average are referred to as countries with high sustainable development performance. In comparison, those with a lower GTFP are referred to as countries with low sustainable development performance. The findings indicate that in Model (7), the regression coefficient associated with the primary explanatory variable, TP, stands at 0.1952, demonstrating statistical significance at the 10% level. In contrast, within Model (8), the regression coefficient for the core explanatory variable TP is 0.0083 and lacks statistical significance. This observation suggests that the BRI exerts a notably more substantial positive influence on the sustainable development of developing countries with higher sustainability performance than those with lower sustainability performance. A possible reason is that countries with high sustainable development performance tend to have more robust infrastructure and technological capabilities. This allows them to better utilize clean energy technologies and green economic development models in the BRI, thereby achieving sustainable development goals. However, for countries with low sustainable development performance countries, issues in their infrastructure, education, governance, etc., may prevent them from fully seizing the opportunities brought by the BRI. For example, they may lack the necessary skills to manage and maintain new infrastructure or be unable to effectively attract and utilize foreign investment.

Model (9) and model (10) classify samples based on their innovation performance. Countries with R&D higher than the sample average are referred to as high-innovation performance countries. Otherwise, they are low-innovation performance countries. The results show that in model (9), the regression coefficient associated with the primary independent variable TP is -0.0225, and its statistical insignificance is evident. In model (10), the regression coefficient of the core explanatory variable TP is 0.1072, and the significance level is 1%. This suggests that the BRI has a more significant positive impact on the sustainable development of developing countries with low innovation than those with high innovation performance. The possible reasons are as follows: First, resource allocation. Developing countries with low innovation performance often have major shortcomings in resource allocation and infrastructure construction. By promoting infrastructure construction and productive capacity cooperation, the BRI helps these countries improve their infrastructure and optimize resource allocation, thereby boosting economic growth. Second, technology transfer and learning: The BRI encourages technological exchanges and cooperation; for developing countries with low innovation performance, this represents a significant opportunity to learn and improve. They can improve their own innovation capabilities by cooperating with more advanced countries and introducing advanced technologies. Finally, market expansion: The BRI has facilitated trade and investment among the countries along its route, providing developing countries with low innovation performance and a broader market space. This attracts foreign investment and helps domestic enterprises go global and tap into new markets.

The samples are categorized according to the level of industrialization in model (11) and model (12). The ones with INS exceeding the average are denoted as highly industrialized countries, and vice versa as lowly industrialized countries. Based on the findings, within model (11), the regression coefficient of the core explanatory variable TP is 0.0571, with a significance level of 10%. In contrast, in model (12), the regression coefficient of TP is 0.0777, with a significance level of 1%. This indicates that the BRI exerts a substantially positive impact on the sustainable development of developing countries witnessing low industrialization levels compared to those with high industrialization levels. Potential reasons include: Firstly, lowly industrial countries often lack sufficient infrastructure, such as roads, railways, and ports. By investing in infrastructure projects, the BRI could significantly ameliorate the transportation conditions of these countries, decrease logistics costs, and thereby elevate their economic development levels. Secondly, lowly industrialized countries often overly rely on exporting primary products, susceptible to fluctuations in international market prices. The BRI tends to aid these countries in developing their manufacturing and service sectors, optimizing industrial structures, and augmenting their abilities to weather exterior risks.

Models (13) and (14) group samples according to the level of development of the financial services industry. Those with an FS higher than the sample average are referred to as developing countries with relatively developed financial services and vice versa. The findings indicate that within model (13), the core explanatory variable TP exhibits a regression coefficient of 0.0664, which is statistically significant at the 10% level. Conversely, in model (14), the regression coefficient associated with TP stands at 0.0675, however, this does not reach a level of statistical significance. This suggests that the BRI has a more evident positive impact on the sustainable development performance of countries with developed financial services. Possible reasons include: Firstly, countries with developed financial services can better enhance financial integration, realizing domestic currency exchange and settlement in both current and capital accounts. This aids in simplifying trade and investment approval procedures and maintaining smooth trade, thereby promoting the economic development of BRI countries. Secondly, countries with developed financial services can provide more funding for infrastructure projects. Thirdly, countries with developed financial services, with stronger product and service innovation capabilities, can provide multiple, multi-layer, and multi-dimensional financial services for BRI construction through differentiated financial service policies, improved domestic and foreign service networks, and enhanced integrated service capabilities. Fourthly, countries with developed financial services have richer experience and capabilities in risk prevention and control, which can comprehensively strengthen risk prevention and control, improve security levels, and ensure the smooth implementation of the BRI. Lastly, countries with developed financial services have an advantage in international communication. By strengthening and improving international communication, it can cultivate a favorable public opinion atmosphere and win more international support for the BRI.

Models (15) and (16) group samples according to the degree of dependence on FDI. Countries with FDI higher than the sample mean are called highly dependent on foreign investment, and vice versa. The outcomes reveal that for model (15), the principal explanatory variable TP has a regression coefficient of 0.1108, which holds significance at the 5% threshold. Meanwhile, in model (16), this variable's regression coefficient is noted as 0.0404, yet it does not attain statistical significance. This suggests that the BRI exerts a more significant positive influence on the sustainable development of developing countries that are highly dependent on foreign investment. Possible reasons include the following: Firstly, the influencing factors of foreign investment encompass the Ownership-Location-Internalization (OLI) paradigm, institutions, national distance, relations, and third countries. Under the BRI, China pays more attention to these factors in its foreign investment to enhance investment efficiency. This implies that developing countries heavily reliant on foreign investment could benefit from higher-quality investments, thereby spurring their sustainable development. Secondly, the BRI aims to build a non-restrictive, non-exclusive pan-regional economic cooperation, providing flexible opportunities for cooperation among countries along its route. This would favor developing countries that heavily depend on foreign investment to attract more financing, promoting economic growth and sustainable development. Lastly, by jointly constructing the Silk Road Economic Belt and the 21st Century Maritime Silk Road, China's goal is to link the developed economies of East Asia and Europe, promoting trade exchanges among countries along the route. This could favor developing countries heavily reliant on foreign investment by extending their exports and increasing foreign exchange income, thereby supporting their sustainable development.

Models (17) and (18) categorize the samples according to energy consumption efficiency, with ES higher than the sample mean being referred to as high energy-consuming countries and the opposite as low energy-consuming countries. The findings indicate that the regression coefficient for the principal explanatory variable TP in model (17) stands at 0.0088 and lacks statistical significance. Conversely, the regression coefficient for the primary explanatory variable TP in model (18) is 0.2169, demonstrating statistical significance at the 1% level. This implies that the BRI has a more significant positive impact on the sustainable development of low-energy-consuming developing countries than high-energy-consuming ones. Possible reasons are as follows: First, the BRI has made a tremendous contribution to global green development and will become the main force promoting global energy transition in the future. For “low energy-consuming” developing countries, this means they have more opportunities to access and use clean, renewable energy, thus achieving sustainable development. Second, the BRI energy cooperation is innovation-led energy cooperation. Around promoting global energy technological transformation, strengthening bilateral and multilateral technology breakthroughs, the application of innovative achievements, building consensus, and promoting multi-party win-win situations. For “low energy-consuming” developing countries, this can not only help them improve energy utilization efficiency but also optimize their energy structure through technological innovation. Finally, the BRI insists on prioritizing ecology and green development, promoting the formation of a new pattern of harmony between man and nature. For “low energy-consuming” developing countries, this presents an opportunity for them to develop their economies in an environmentally friendly and sustainable way, avoiding the repetition of the development patterns of “high energy-consuming” countries, hence achieving sustainable development.

**Table5:** Heterogeneity Analysis

| | (5) | (6) | (7) | (8) |
|---|---|---|---|---|
| | high income | lower income | High sustainable development performance | Low sustainable development performance |
| TP | -0.0481 | 0.0623* | 0.1952* | 0.0083 |
| | [-1.0789] | [1.8589] | [1.9400] | [1.0795] |
| _cons | 0.3434*** [26.7269] | 0.3848*** [53.5760] | 0.6244*** [38.9237] | 0.2153*** [93.8856] |
| | **(9)** | **(10)** | **(11)** | **(12)** |
| | High innovative performance | Low innovation performance | High degree of industrialization | Low level of industrialization |
| TP | -0.0225 | 0.1072*** | 0.0571* | 0.0777*** |
| | [-1.3572] | [6.0505] | [2.1529] | [4.6829] |
| _cons | 0.3635*** [56.7267] | 0.3618*** [217.8865] | 0.2708*** [36.5548] | 0.4049*** [105.7489] |
| | **(13)** | **(14)** | **(15)** | **(16)** |
| | Developed financial services industry | Underdeveloped financial services | High dependence on inward investment | Low dependence on inward investment |
| TP | 0.0664* | 0.0675 | 0.1108** | 0.0404 |
| | [2.0214] | [1.5623] | [2.5789] | [1.3554] |
| _cons | 0.3536*** [43.6091] | 0.3407*** [30.8135] | 0.3187*** [39.8898] | 0.3647*** [40.3211] |
| | **(17)** | **(18)** | | |
| | high energy consumption | Low energy consumption | | |
| TP | 0.0088 | 0.2169*** | | |
| | [0.6984] | [3.5237] | | |
| _cons | 0.3016*** [82.7547] | 0.3771*** [28.6836] | | |

*t* statistics in brackets

$^{*}$ $p < 0.1$, $^{**}$ $p < 0.05$, $^{***}$ $p < 0.01$

### 5.3. Conclution

In our research and analysis of multiple participating countries in the BRI, we found that China's BRI proposal has a significant positive impact on the sustainable development performance of these countries. Particularly for low-income and less industrialized developing countries, their development performance has notably improved with the implementation of this initiative. We found that the impact of this initiative on countries with more developed financial services and a higher dependence on foreign investment is also significant. Surprisingly, the initiative has a more pronounced positive impact on low-energy-consuming countries. Despite the extensive positive impacts of the BRI, we also need to recognize that to obtain better outcomes, we need to design and implement policies that are more finely tuned to the specific conditions of each country. For countries with high energy consumption, high degrees of industrialization, or higher incomes, we need to offer more targeted policy strategies for them to benefit better from this initiative.

## 6. Policy Suggestions

The BRI is a global development strategy proposed by the Chinese government, aiming to strengthen regional interconnection and create a better future. It is a significant step towards economic globalization, offering a way to cope with the myriad of challenges and opportunities in the 21st century. According to the empirical results of this study, the BRI has produced considerable positive impacts on the sustainable development performance of developing countries. It has paved the way for sustainable development of society and the environment. However, it must be recognized that the benefits brought about by the BRI are not evenly distributed. Its impact is influenced by multiple factors such as income level, industrialization, financial service development, dependence on foreign capital, and energy consumption patterns. We propose a comprehensive policy recommendation to optimize the results of the BRI and ensure its role as a catalyst for sustainable development.

### 6.1. Provide targeted support for low-income countries

In light of the higher positive impacts of the BRI on low-income countries, it is recommended that investment and technical support be increased in these nations. This can be done through offering preferential loans, aid programs, and human resource training to help these countries improve infrastructure, education, and health conditions, thereby promoting economic growth and social development. Specifically, by providing low or even interest-free loans, these countries can lower their financing costs, making it easier for them to initiate and implement key infrastructure projects, such as roads, bridges, and power grid constructions. Additionally, aid programs can be used to enhance the developments in education and health, such as donating school buildings, providing medical equipment, or sending expert teams for technical guidance and training. Such measures not only help the target countries improve people's livelihoods and raise living standards but also create local jobs and stimulate economic growth. Meanwhile, through human resource training, the skill levels of the local workforce can be enhanced, laying a solid talent foundation for their future sustainable development. This all-around support will contribute to a win-win cooperation model, which, while promoting the social and economic development of low-income countries, also creates a more stable external environment for the deep implementation of the BRI.

### 6.2. Focusing on countries with high sustainable development performance

Since the BRI has a more substantial impact on countries with higher sustainable development performance, consideration should be given to establishing closer partnerships with these countries. This includes sharing best practices, strengthening policy dialogue, and promoting bilateral or multilateral cooperative projects, thus providing success cases for other participating countries. For instance, strategies for effectively managing and implementing cross-border infrastructure projects could be shared, or ways to balance environmental protection with promoting economic growth. Besides, strengthening policy dialogues is another method; by holding regular meetings and seminars, countries can exchange ideas on better coordinating policies and plans to adapt to global economic changes. Such dialogue helps to form consensus and promotes the formulation of more effective regional development strategies. Promoting bilateral or multilateral cooperation projects is also crucial. This may include joint investment in specific infrastructure projects like roads, railways, ports, and telecommunication networks or collaboration in areas like education and technology transfer. Through these specific projects, participating countries can not only gain direct economic benefits but also improve their own development level by learning and imitating the practices of more advanced countries.

### 6.3. Enhancing technology and knowledge transfer to low innovation performance countries

Given that the BRI has a greater positive impact on countries with low innovation performance, high innovation performance countries can assist these countries in enhancing their local innovation capacities and technological levels by providing technological assistance, training, and education cooperation. Countries with high innovation performance can dispatch expert teams to these countries for on-site guidance and share their advanced experiences and technologies in high-tech fields such as artificial intelligence, biotechnology, and green energy. Meanwhile, they can also invite technicians from these low innovation performance countries to participate in short-term or long-term training programs in high innovation performance countries, learning the successful practices in the fields of urban planning, modern agriculture, and digital economy. Besides, high-performance countries can set up joint research and development centers with these countries, jointly conducting targeted technology research and innovation projects to address specific local problems.

## 6.4. Industrialization and Infrastructure Development

For countries with low levels of industrialization, the BRI seems to have a more pronounced impact on their sustainable development performance, which suggests that countries with lower industrialization levels tend to have a larger room for improvement in their sustainable development performance. These countries often have abundant natural and labor resources, but due to restrictions in technology, capital, management, and other aspects, they find it difficult to exploit these resources effectively to leapfrog industrialization. Therefore, the BRI can significantly improve these countries' sustainable development achievements through promoting infrastructure construction, strengthening trade links, and providing financial support. For instance, through the BRI, China has established several overseas economic and trade cooperation zones with participating countries, usually including the construction of industrial parks. Within these industrial parks, not only necessary infrastructure like roads, electric power supply, and water supply are provided but also advanced production technologies and management experience are introduced, offering local enterprises a platform for learning and growth. Concurrently, targeted human resource training, such as skills and management training, is provided to enhance the quality of the local labor force, foster employment, and promote the optimization and upgrade of industrial structure.

**Author contributions statement**

I declare that the article is my personal creation, without other authors, and does not use any AI tools.

**Conflict of Interest Declaration**

I declare that there is no conflict of interest in this article.

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# Appendix A

**Table A:** Abbreviations and their full spellings

| Abbreviation | Full spelling of the abbreviation |
|---|---|
| BRI | Belt and Road Initiative |
| SBM | Slacks-Based Measure |
| GTFP | Green Total Factor Productivity |
| DID | Difference in Differences |
| TFP | total factor productivity |
| APO | Asian Productivity Organization |
| DDF | Directional Distance Function |
| DEA | Data Envelopment Analysis |
| DMUs | Decision Making Units |
| GDP | Gross Domestic Product |
| PGDP | Per Capita Gross Domestic Product |
| FS | financial sup-port |
| R&D | research and development |
| FDI | foreign direct investment |
| INS | industrial structure |
| ES | energy consumption structure |
| TFE | time-fixed effects |
| FE | Fixed Effects |
| HDFE | High Dimensional Fixed Effects |
| CAC | China-Africa Cooperation |
| SDGs | Sustainable Development Goals |
| WIND | Wind Information Database |
| TP | Trade Surplus |
| OLI | Ownership-Location-Internalization |