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How business environment of countries along the Belt and Road impacts China's OFDI efficiency: a stochastic frontier gravity model approach

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The Belt and Road Initiative (BRI) provides a new opportunity for the continued deepening of economic and trade cooperation between China and countries along the BRI route. However, different business environments among countries have led to the problem of a low and uneven distribution of China's overall trade and investment efficiency in the countries along the route. Using the stochastic frontier gravity model, this study evaluates the efficiency of China's outward foreign direct investment (OFDI) based on the data of 47 countries along the Belt and Road route from 2013 to 2019. The empirical results indicate that the efficiency level of China's OFDI in countries located along the Belt and Road route is 43.39%, which suggests a regional imbalance. In terms of business environment factors, regulatory governance, civic discourse, government accountability, and regulatory quality in host countries have a positive impact on China's OFDI. The positive effects of the BRI have enabled Chinese enterprises to better face factors such as political instability, corruption and imperfections in the legal system when investing abroad. The findings and suggestions could help the governments and enterprises of the countries along the route improve the business environment in a more targeted manner, enhance the space for economic and trade cooperation, and promote the common development of the countries along the route.

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Introduction

Since President Xi Jinping put forward the major initiatives of building the Silk Road Economic Belt and the 21st Century Maritime Silk Road during his visit to Central Asia and Southeast Asia in 2013, the initiative has attracted enthusiastic responses from many countries. By 2020, China's outward foreign direct investment (OFDI) in countries or regions located along the Silk Road reached $153.712 billion, up 12.3% year-on-year, ranking first in the world and achieving remarkable results in boosting world economic growth.

While the Belt and Road Initiative (BRI) has achieved results that have attracted the world's attention, it has also encountered challenges from all sides (Ye Hailin, 2019). Traditional economic factors, as well as the political, especially institutional, factors of the host country, have become important, affecting China's OFDI; in addition, the business environment, as an important part of the institutional environment, is naturally closely related to China's OFDI (Chen and Yong, 2021). The business environment has a systematic impact on the transaction costs of a country's OFDI in terms of both the institutional environment and institutional arrangements, and a convenient business environment also has become an important impact on a country in terms of its competitiveness (Huang and Qiao, 2018). The higher the institutional quality of the host country is, the more attractive it is to China's OFDI (Belgibayeva and Plekhanov, 2019). Currently, to optimize the business environment and attract host countries to invest in China, countries worldwide are committed to the reform of the political system and the reform of the commercial system (Chen and Yong, 2021).

Although the BRI has won the respect of most countries, and the data show that most countries participating in the construction of the BRI are developing well and making obvious progress, the BRI is also facing great challenges. There have been cancellations of multilateral investment agreements (MIAs), regional investment agreements (RIAs), and bilateral investment agreements (BITs) globally in recent years, and the international institutional environment has become increasingly complex and unstable. The level of economic development of the countries located along the route is uneven, and their internal and external environments are also quite different. Therefore, we started to think about how different business environments affect the efficiency of China's OFDI in particular. What is the efficiency of China's investment in countries along the Belt and Road? How should China optimize its investment layout in countries along the Belt and Road?

Based on these questions, this paper evaluates the overall efficiency of China's OFDI through empirical analysis based on panel data from 47 countries located along the Belt and Road route from 2013 to 2019. We hope that by clarifying the logical relationship between the host country's business environment and the efficiency of China's OFDI at the theoretical level, we can further provide certain policy suggestions to optimize the business environment and improve the efficiency of China's OFDI trade.

The remaining sections of this study are organized as follows. Section "Literature review" reviews the relevant literature; Section "Theoretical model" describes the theoretical model; Section "Econometric model and data interpretation" presents the econometric model and data description; Section "Empirical test and analysis" analyzes the results based on empirical tests; and Section "Conclusions and suggestions" concludes the paper and offers suggestions.

Literature review

OFDI motives and influencing factors. Dunning (1979) advocated analyzing the purpose and conditions of OFDI and the ability of OFDI together; based on adopting Heimer's monopoly advantage theory and Buckley's and Carson's internalization theories, he introduced the theory of location advantage. After synthesizing the theories, Dunning created the compromise method and framework, forming the compromise theory of international production, which explains the motivation of OFDI. Tinbergen (1962) established a theoretical hypothesis by utilizing Newton's formula of universal gravitation in classical mechanics. The theory holds that the size of the total trade between two countries is proportional to the national income of the two countries and inversely proportional to the distance between the two countries; thus, trade is more likely to occur between geographically proximate countries, which better explains the phenomenon of high concentration of intraindustry trade in modern trade. Regarding the influencing factors or role mechanisms of China's OFDI, recent academic research is extensive. Buckley, through empirical analysis, found that host country market size, geographic distance, and other factors are closely related to China's OFDI (Buckley et al., 2009). Zhang Li, using the expansion of the gravity model, found that the host country's geographic distance and China's outward foreign direct investment are significantly negatively correlated with the host country's GDP; furthermore, labor market efficiency and technology readiness level are significantly positively correlated with China's OFDI (Zhang Li, 2019). However, in recent years, the perspective of OFDI has gradually shifted in the direction of the system, and scholars have begun to conduct in-depth investigations of the host country's macro system and the micro business environment factors affecting the operation of enterprises.

Research on business environment. In a narrow sense, the business environment comprises the various institutional rules involved in the entry, production and operation, and exit processes of market players, such as the indicators involved in the World Bank's report on doing business (dealing with construction permits, registering property, cross-border trade, enforcing contracts, etc.). In a broad sense, the business environment is the investment environment, that is, the country financing the investment activities, which affects the investment behavior of the host country due to the sum of the various investment environments, adding numerous macro, noninstitutional factors of influence. The business environment indicators provided by the World Bank converge to the latter sense and are currently used by many scholars as a source of data with strong authority; therefore, this paper will use the six business environment indicators included in the World Bank Government Index as trade nonefficiency term variables.

Research on the impact of business environment on OFDI. Research on the relationship between the host country's business environment and domestic OFDI has attracted an increasing level of attention from scholars; however, what is the relationship between the host country's business environment and home country OFDI? Is it a facilitator or a hindrance, or is it irrelevant? To date, relevant studies have not reached a consensus. Dollar et al. (2006) found that the business environment, in terms of infrastructure, financial services, customs clearance efficiency, and government management, has a positive effect on firms' exports, such that the better the business environment is, the larger and wider the scale and scope of firms' exports. Tuaño et al. (2014) argue that there are also differences in the business environments within countries. The better the business environment is, the stronger the firms' motivation to export and the larger the scale of exports. At the same time, local governments

Table 1 Comparison of DEA and SFA.

Methodology	Feature	Representative literature
DEA	Multiple inputs and outputs can be measured and are not affected by the scale; an evaluation of efficiency can be made, but it is not possible to explore the causes of efficiency losses; and DEA is a deterministic frontier method, which does not account for the impact of stochastic factors and does not allow for the measurement of multiple outputs.	Xu and Sim (2022); Lukić and Kozarevic (2019); Diao et al. (2016)
SFA	The problem of randomly perturbed terms can be solved, the effect of statistical noise is accounted for, and it is possible to both derive specific efficiency values and explore the sources of efficiency losses.	Gong et al. (2022) Ravishankar and Stack (2014) Zhu (2023) Jiang et al. (2022) Li and Li (2015) Yan and Hu (2016)

can also continuously optimize the business environment in the region to attract more capital. However, some scholars have indicated that the host country's business environment does not always have a significant positive effect. For example, the research results of Li F. et al. (2018) show that in countries located along the Belt and Road route, the impact of the host country system on China's overseas investment is significantly negative; thus, China prefers to invest overseas in countries with poorer host country systems. Kolstad and Wiig (2012) argued that good host country systems may serve as a certain impediment to the home country's OFDI to some extent. At the same time, there is a third view known as "institutional irrelevance", which argues that the level of host country institutions is not directly related to home countries' OFDI (Hines, 1995; Henisz, 2000; Chao, 2012).

Research on the Belt and Road Initiative and China's outward foreign direct investment. The literature contains a series of studies on the effects of China's OFDI under the BRI using various samples and modeling approaches; however, there is no current consensus on the findings. Shao (2020) pointed out that the BRI stimulates China's OFDI mainly through a mechanism that mitigates the negative impact of political risk. Yu et al. (2019) found that the BRI promotes China's OFDI flows to developing countries that support the initiative and that this effect is particularly important for developing countries with less attractive markets and institutional environments. In contrast, Nugent and Lu (2021) found that the BRI does not have a significant impact on China's OFDI, probably because the BRI does not create enough political incentives for Chinese multinationals, and the international community is not interested in it. Furthermore, international objections to Belt and Road investments may make the countries involved more cautious about China's OFDI.

Studies related to stochastic frontier gravity modeling. Stochastic frontier analysis was first proposed by Meeusen and van den Broeck (1977) to solve the problem of production efficiency, explaining that technical inefficiency in the production function refers to the loss of production efficiency caused by human factors in the production process. Pitt and Lee (1987) used stochastic frontier analysis to solve the problem of enterprise production efficiency; the authors later expanded the approach to include the research level of foreign trade efficiency, which is still widely used. At present, scholars both at home and abroad adopt data envelopment analysis (DEA) and stochastic frontier analysis (SFA) to measure the efficiency or investment potential of China's outward foreign direct investment (OFDI). Table 1 shows a comparison of the advantages and disadvantages of the two methods.

At present, SFA is used to study the efficiency of OFDI along the Belt and Road route in a more representative way. Deng et al. (2019) examined the impact of the foreign investment policy coordination of countries located along the Belt and Road on China's OFDI from the perspective of bilateral and multilateral investment policy coordination using panel data from China's direct investment in 54 countries located along the Belt and Road from 2008 to 2017. The authors found that the BIT and joining the International Center for Settlement of Investment Disputes (ICSID) have a negative impact on China's OFDI. Yan et al. (2019) used the time-varying stochastic frontier gravity model, took the global governance indicators as the technical inefficiency term, and found through empirical analysis that China's current OFDI efficiency is low, showing positive time-varying effects, smooth growth, and spatial convergence adjustments. Furthermore, the authors found that the efficiency of the investment in the "All Along the Way" is better than that of the "Belt". Furthermore, the efficiency of investment in "One Belt" is better than that in "One Road".

By combining the literature, the marginal contribution of this paper can be divided into the following two aspects. First, in the measurement model, the stochastic frontier gravity model introduces time-varying factors. Although the traditional DEA method can be used to measure and evaluate trade efficiency, it is unable to be used to determine the factors that cause the loss of trade efficiency; it also does not account for the influence of stochastic factors. In contrast, the SFA method used in this paper incorporates the random interference term, which not only measures trade efficiency but also derives the factors that cause the loss of efficiency and their weights. Second, excluding the missing data and utilizing the panel data of 47 countries located along the Belt and Road route and the relevant control variables, the research sample has certain regional characteristics and typicality by focusing on the direct investment in the countries located along this route. This makes the research sample display certain regional characteristics and typicality. Third, regarding the selection of core explanatory variables, few scholars have studied the impact of the host country's business environment on the efficiency of China's OFDI. Combining theoretical analysis and literature support, this paper uses the six indicators defined by the World Bank's government index to obtain the variables of government stability, business regulation, and legal system in three dimensions and introduces them into the technical inefficiency term affecting OFDI for empirical research; this approach expands the research on the relationship between the institutional environment and the efficiency of OFDI to a certain extent.

Theoretical model

The gravitational model originated from Newton's law of gravity, on which Tinbergen (1962) built the traditional classical gravitational model in 1687 to explain the way humans interact and influence each other economically, socially, and politically in

geographical space, which was later used in the field of international trade. However, the traditional frontier gravity model ignores the disturbance of the random disturbance term; thus, Meeusen and Van den Broeck (1977) and Aigner et al. (1977) added the effect of statistical noise to refine it. Combining the traditional frontier gravity model assumptions, $V_{jt} \sim N(0, \sigma_V^2)$, the stochastic frontier gravity model was obtained as follows:

$$\text{ofdi}_{jt} = f(x_{jt}\beta)\exp(v_{jt}) \tag{1}$$

In the OFDI process, there are various factors that will lead to the loss of investment efficiency. Thus, a technical inefficiency term u_{jt} with nonnegative and normally distributed characteristics is introduced based on Eq. (1); this term affects the amount of outward investment between two countries and can be expressed as follows:

$$\text{ofdi}_{jt} = f(x_{jt}\beta)\exp(v_{jt})\exp(-u_{jt}) \tag{2}$$

When there is no efficiency loss, the amount of investment between the two countries will reach the optimal level ofdi_{jt}^{*}. Current period OFDI efficiency TE_{jt} is the ratio of actual OFDI ofdi_{jt} to ideal OFDI ofdi_{jt}^{*}:

$$\text{TE}_{jt} = \frac{\text{ofdi}_{jt}}{\text{ofdi}_{jt}^{*}} = \exp(-u_{jt}) \tag{3}$$

It is not difficult to find that $0 < \text{TE}_{jt} \le 1$; when $\text{TE}_{jt}=1$, there is no trade efficiency deficit, and the actual OFDI reaches the optimal value at this point. When TE_{jt} tends to zero, the trade efficiency loss is more serious, and China's OFDI in that country is less efficient. The linear stochastic frontier gravity model is obtained according to Battese and Coelli's (1995) one-step disentanglement of the technical inefficiency term:

$$\ln \text{ofdi}_{jt} = \ln f(x_{jt}) + v_{jt} + az_{jt} - w_{jt} \tag{4}$$

Equation (5) is used to test the applicability of the stochastic frontier gravity model to the study population.

$$\text{LR} = -2\{\ln[L(H_0)/L(H_1)]\} = -2\{\ln[L(H_0) - L(H_1)]\} \tag{5}$$

where $L(H_0)$ and $L(H_1)$ are the likelihood values under the null and alternative hypotheses, respectively. It is generally believed that the LR test statistic obeys a mixed chi-square distribution with certain degrees of freedom; thus, the LR statistic obtained from the model regression can be compared with the critical value of the mixed chi-square distribution table to determine whether it is necessary to use a stochastic frontier gravity model that introduces inefficiency factors.

Econometric model and data description

Based on the above construction of the stochastic frontier gravity model, this section draws on the choice of China's OFDI stochastic frontier variables by Hu et al. (2017), Li and Li (2015), Li and Li (2017), and Wang (2019) to construct the following model:

$$\begin{aligned}\ln \text{ofdi}_{jt} = {} & \beta_0 + \beta_1 \ln \text{cgdp}_i + \beta_2 \ln \text{gdp}_{jt} + \beta_3 \ln \text{dist}_j + \beta_4 \text{open}_{jt} \\ & + \beta_5 \text{hightec}_{jt} + \beta_6 \text{econfr}_{jt} + \beta_7 \text{lang}_j + \beta_8 \text{bit}_{jt} + v_{jt} = u_{jt}\end{aligned} \tag{6}$$

where v_{jt} is the random error term, which follows a normal distribution; u_{jt} is the technical inefficiency term; β_i is the coefficient to be estimated for each variable; and each random frontier variable is described as shown in Table 2.

ofdi_{jt} denotes the current flow of China's direct investment in country j in period t; the data are obtained from the Bulletin of China's Outward Foreign Direct Investment in previous years. cgdp_t denotes the country's GDP in period t, which is used to measure the size of the domestic economy using data from the World Bank. gdp_{jt} denotes the GDP of country j in period t, which measures the total size of the host economy using data from the World Bank. dist_j is the straight-line distance between the two capitals, which is used to measure investment distance and is obtained from both the database of the Center for International Studies (CEPII), which is a regulatory think tank and the official website of Baidu. open_{jt} denotes the trade dependence of country j along the Belt and Road in period t, which is expressed as (total exports + total imports)/GDP and used to measure the degree of openness of the host country to the outside world using data from the World Bank. hightec_{jt} is the technology level of the countries located along the Belt and Road route, which is expressed as the share of high-tech exports in manufactured exports and is used to measure the supporting power of the host country's economic development using data from the World Bank. econfr_{jt} indicates the degree of economic freedom, which is weighted by ten indicators, namely, freedom of investment, financial freedom, trade freedom, labor freedom, monetary freedom, business freedom, financial freedom, property rights, freedom from corruption, and government spending in the host country; this variable measures the degree of government intervention in the economy, which ranges from 0 to 100 according to the Wall Street Journal and the annual report of the Heritage Foundation such that the higher the value is, the better the economic environment and, in general, the more favorable for investment in the home country. Using data from the National Online Project, lang_j indicates whether the two countries share a common language, with English as the second language of China taking a dummy value of 1 when the official language of the host country is English and 0 otherwise; in general, communication costs will be significantly reduced when the two countries share a common language. bit_{jt} is a dummy variable indicating whether China signed a bilateral investment agreement with country j along the route in year t, and it took effect; this variable has a value of 0 in the year before t and a value of 1 thereafter. The signing of a bilateral investment agreement between a country located along the route and China will promote China's direct investment in that country, which means that the above-mentioned variable is an investment promotion factor. v_{jt} denotes the unobservable random error term affecting China's direct investment in country j in period t, consistent with a white noise process. u_{jt} is the adjustable technical inefficiency term introduced in this study, which fits the normal truncated distribution and represents all unobservable inefficiency factors; its value will have the most intuitive sorting effect on the efficiency of China's OFDI to the host country.

Notably, China's OFDI flows in the form of explanatory variables may not all be positive; thus, there is a need to consider positive and negative issues when taking logarithms of these variables. To overcome these problems, these variables are treated using a log-transformation model, drawing on Wu et al. (2020):

$$L(x) = \text{sign}(x) \times \log(|x| + 1) \tag{7}$$

Regarding the setting of the investment inefficiency equation, this study creatively incorporates the laws and regulations of the business environment, business regulation, government stability, and nonnatural factors, including social factors, into the technical inefficiency equation and obtains the following equation:

$$\begin{aligned}u_{jt} = {} & a_0 + a_1 \text{voice}_{jt} + a_2 \text{pol}_{jt} + a_3 \text{govt}_{jt} + a_4 \text{regu}_{jt} \\ & + a_5 \text{rl}_{jt} + a_6 \text{ctrl}_{jt} + w_{jt}\end{aligned} \tag{8}$$

The most important core explanatory variables affecting the investment inefficiency term are the business environment as defined by the World Bank, which affects the entire process of business operations, i.e., the six indicators corresponding to the

Table 2 Variable description.

Variable	Description	Unit	Coefficient	Data source
$ofdi_{jt}$	OFDI flows from China to country j located along the Belt and Road route in period t	10,000 dollars		China Outbound Direct Investment Statistical Bulletin
$cgdp_t$	China's gross domestic product	10,000 dollars	β_1	World Bank
gdp_{jt}	GDP of countries located along the Belt and Road route	10,000 dollars	β_2	World Bank
$dist_j$	Geographical distance between two countries	km	β_3	Distance between two capitals
$open_{jt}$	Trade dependence of country j located along the Belt and Road route in period t	%	β_4	World Bank
$hightec_{jt}$	Technology level of countries located along the Belt and Road route	%	β_5	World Bank
$econfr_{jt}$	Economic Freedom Index	0–100	β_6	Wall Street Journal; Heritage Foundation Annual Report
$lang_j$	Whether the two countries share a common language	0/1	β_7	National Online Project
bit_{jt}	In year t, China signs a bilateral investment agreement with country j located along the route, and it comes into force; the year before t is assigned a value of 0 and the year afterward is assigned a value of 1	0/1	β_8	Official website of the Department of Treaty and Law of the Ministry of Commerce

Table 3 Description of technical inefficiency term variables.

Variable		Description	Value range	Coefficient	Data Sources
Business environment		Five indicators included in the World Bank Government Index were selected			World Bank Government Index (WGI)
Government stability	$voice_{jt}$	Civic discourse and government accountability in t-periods in country j located along the route	−2.5 to 2.5	a_1	World Bank Government Index (WGI)
	pol_{jt}	Political stability in country j located along the route in period t	−2.5 to 2.5	a_2	World Bank Government Index (WGI)
	$govt_{jt}$	Government efficiency in period t for country j located along the route	−2.5 to 2.5	a_3	World Bank Government Index (WGI)
	$ctrl_{jt}$	The degree of corruption control in period t in country j located along the route	−2.5 to 2.5	a_6	World Bank Government Index (WGI)
Business regulation	$regu_{jt}$	Regulatory quality of country j located along the route in period t	−2.5 to 2.5	a_4	World Bank Government Index (WGI)
Legal system	rl_{jt}	Legal rules for country j located along the route in period t	−2.5 to 2.5	a_5	World Bank Government Index (WGI)

World Bank Government Index. These six indicators explain three categories of government stability, business regulation, and legal system.

As shown in Table 3, u_{jt} denotes the inefficiency factor that hinders the frontier volume of trade and investment. H_0 is the random disturbance term. a_0 is the constant term of the technical inefficiency term, and a_i $(0 < i < 6)$ is the coefficient of the explanatory variable of interest. The first four indicators fall under the category of government stability, reflecting the impact of the quality of government governance on the country's economic development and social welfare level, with higher scores for the indicators representing lower levels of interference with the level of governance.

$voice_{jt}$ denotes civic discourse power and government accountability in period t in country j located along the route, measuring the level of democracy in the host country. The coefficient of this variable is expected to be negative.

rl_{jt} represents the legal system by indicating the legal rules of the countries located along route j in period t and measuring the level of institutional security of the host country's economic operation. If the host country's legal rules are overdeveloped, this may lead to more formalities and higher threshold barriers for enterprises to undertake OFDI. It may become a burden for investing enterprises, thus affecting trade efficiency. Therefore, the coefficient on the level of legal rule protection is expected to be positive.

pol_{jt} indicates the political stability of country j located along the route in period t, measuring the objective environment for economic development in the host country. Generally speaking, most Chinese multinational enterprises are state-owned enterprises that enjoy various favorable policies such as risk guarantees, financial subsidies, and tax incentives given by the government. This will increase the ability of multinational enterprises to bear political risks and reduce their requirements for the political stability of the host country; in addition, countries along the route with low political stability may actively seize the strategic opportunity of the "Belt and Road" and provide various preferential policies to attract Chinese enterprises to carry out investment activities (Pan et al., 2019). Therefore, the coefficient of this variable is expected to be positive.

$govt_{jt}$ denotes the efficiency of the government in period t in country j located along the route. Enterprises face various links in the production and operation process; thus, the abovementioned variable represents the number of obstacles in each link and the efficiency of government processing. The coefficient of this variable is expected to be negative.

$ctrl_{jt}$ not only indicates the level of corruption in country j located along the route in period t but also measures the level of integrity of the host government. A strict degree of corruption control may have a negative impact on the conduct of OFDI in China. While corruption may inhibit firms from undertaking OFDI to a certain extent, it also has a lubricating effect on investment transactions. This effect can help mitigate the impediments to transactions brought about by institutional irrationalities and bureaucratic inefficiencies. Therefore, the coefficient of this variable is expected to be positive.

$regu_{jt}$ indicates the quality of business regulation in country j located along the route in period t and measures the level of well-functioning markets and fair competition in the host country. The higher the business regulation score, the simpler the procedures investors need to go through in the various business segments, and the smaller the investment costs for the firm are likely to be. Therefore, it is hypothesized that the resulting loss of investment efficiency is also likely to be smaller, and the business regulation quality coefficient is expected to be negative.

rl_{jt} represents the legal system by indicating the legal rules of the countries located along route j in period t and measuring the level of institutional security of the host country's economic operation. If the host country's legal rules are overdeveloped, this may lead to more formalities and higher threshold barriers for enterprises to undertake OFDI. It may become a burden for investing enterprises, thus affecting trade efficiency. Therefore, the coefficient on the level of legal rule protection is expected to be positive.

In terms of sample selection, due to the rich data indicators and long time series, the content that can be found in the World Bank's official website, the 2020 Business Environment Report and related trade websites is limited. Thus, excluding the countries and regions with missing data, this study finally selects 47[1] countries as the sample of countries located along the Belt and Road route.

The sample interval ranges between 2013 and 2019, mainly because the BRI was proposed in 2013, and the latest data of various indicators were not updated until 2019; thus, the above years are chosen as the time series. In addition, the new coronavirus disease (COVID-19) attack in 2020 hampered trade development in various countries; thus, the data from before 2013 and from 2021–2022 may have extreme values, which would affect the empirical evidence.

Empirical test and analysis

We use Frontier 4.1 to conduct regression analysis on the sample observations using the following steps. First, a simple descriptive analysis and multiple covariance test are conducted to determine the reasonableness of the data. Second, the applicability of the analytical model is tested, and the necessity of introducing time-varying factors and technical inefficiency terms is considered. Then, a simultaneous time-varying stochastic frontier analysis and technical inefficiency analysis are conducted for the relevant countries to derive the values of trade efficiency and the influence factors of the relevant variables for each country and to determine the change in the direction of time-varying factors and technical inefficiency factors in the model according to efficiency. Then, we conduct simultaneous time-varying stochastic frontier analysis and technical inefficiency analysis for the concerned countries to not only derive the values of trade efficiency and the factors influencing the related variables for each country but also judge the change in the direction of time-varying factors and the potential space under the hindrance of technical inefficiency factors in the model according to the change in efficiency.

Table 4 Results of the descriptive analysis.

Variable	N	Mean	s.d.	Min	Max
lnofdi	329	3.355	2.403	−4.660	6.721
lncgdp	329	16.26	0.153	16.07	16.47
lngdp	329	11.22	1.656	6.629	14.59
lndist	329	8.830	0.488	7.062	9.635
open	329	0.925	0.645	0.207	3.801
hightec	329	0.0910	0.124	0	0.603
econfr	329	61.29	10.02	28.60	89.40
contig	329	0.0850	0.279	0	1
lang	329	0.213	0.410	0	1
bit	329	0.745	0.437	0	1
voice	329	−0.143	0.878	−1.880	1.630
pol	329	−0.0850	0.940	−2.600	1.620
govt	329	0.0390	0.831	−1.300	2.230
regulation	329	0.0520	0.857	−1.900	2.230
rule	329	−0.0170	0.853	−1.580	2.010
control	329	−0.0220	0.895	−1.400	2.340

Descriptive statistical analysis and multicollinearity test. Table 4 shows that the economic freedom, GDP, and OFDI flow of China vary greatly among the countries located along the Belt and Road route, which indicates that the economic development level and business environment quality of each country vary greatly. The results of multicollinearity testing show that the average multicollinearity of all variables is 6.79, which is less than 10; thus, there is no serious multicollinearity problem among the variables.

Model applicability test. We test the existence of the technical inefficiency term based on Eq. (5), and the results are shown in Table 5. The LR statistic obtained through model regression is greater than the critical value at the 5% significance level; thus, the original hypothesis is rejected.

Time-varying model test. The time-varying model indicates whether the trade inefficiency term changes over time and has a hindering effect on the frontier variables. In this study, we test whether the technical inefficiency term changes over time based on Eq. (5) and the results are shown in Table 6. The LR statistic obtained by model regression is greater than the critical value at the 5% significance level; thus, the original hypothesis is rejected. In other words, the data are time varying. Therefore, the data are suitable for introducing stochastic frontier gravity models for analysis and research.

Empirical results of the time-varying stochastic frontier gravity model. The stochastic frontier surface and technical inefficiency terms are analyzed using Frontier 4.1, and the confidence level of the results is shown in Table 7. The gamma values converge to 1, indicating the correctness of the model; i.e., the difference between the stochastic frontier quantity and the actual quantity mainly comes from the inefficiency term rather than from the stochastic disturbance term.

In this study, we introduce time-varying factors and technical inefficiency factors to analyze the panel data of 47 countries and regions located along the Belt and Road, after which we obtain the regression coefficients and t values of each explanatory variable,

Table 5 Results of the model applicability test.

H_0 hypothesis	H_0	H_1	LR	5% threshold value	Result
No inefficiency term exists	−735.67396	−730.46751	10.4129	5.99	Reject

Table 6 Results of the time-varying model test.

H_0 hypothesis	H_0	H_1	LR	5% threshold value	Result
No time-varying	−735.67396	−730.46193	10.42406	7.81	Reject

Table 7 Coefficient estimates from the Frontier 4.1 output.

Explanatory variable	Coefficient	Standard-error	*t*-ratio
beta 0	33.813321	1.4077569	−24.019290
beta 1	2.5277056	0.10263415	24.628310
beta 2	0.11435768	0.031311025	3.6523137
beta 3	−0.36340151	0.088729252	−4.0956223
beta 4	0.39092449	0.059247311	6.5981811
beta 5	0.55093817	0.27761327	1.9845528
beta 6	−0.015912717	0.0047251542	−3.3676609
beta 7	0.28632956	0.10448177	2.7404738
beta 8	0.19210843	0.13955758	1.3765532
alpha 0	−42.385208	3.3701971	−12.576477
alpha 1	−7.6538757	0.89100236	−8.5901856
alpha 2	11.066358	1.0831951	10.216403
alpha 3	−15.862260	1.3933349	−11.384384
alpha 4	−6.5926358	0.88155237	−7.4784392
alpha 5	0.043246160	0.90893360	0.047579009
alpha 6	11.673442	1.0721806	10.887570
sigma-squared	74.046513	5.4345847	13.625055
gamma	0.99908792	0.00028402257	3517.6356

as shown in Table 7. In this study, a *t*-test of all the variables is conducted at the 5% confidence level; it is found that variables representing the technology level of the countries located along the Belt and Road and whether the countries have signed a bilateral investment agreement with China are not significant. The nonsignificant level of technology in the countries located along the Belt and Road route may be the result of most of the countries and regions located along the route having technologically and economically backward economies, which provides room for the development of China's OFDI. Whether the countries have signed a bilateral investment agreement with China is probably nonsignificant because most of the countries located along the Belt and Road route already have such agreements with China, suggesting that trade facilitation has improved since the beginning of the period. Furthermore, China's direct investment in developing countries is mainly aimed at obtaining stable resource supply or developing markets (Zhong and Fan, 2016); thus, whether bilateral investment agreements have been signed is not the most important factor.

The variables tested for significance are, in descending order of influence, China's GDP, the host country's level of trade dependence, the geographical distance between the two countries, whether the two countries share a common language, the host country's GDP, and the host country's level of economic freedom. The positive coefficient and largest value of China's GDP indicate that the larger China's economy is, the more practical OFDI is, which further supports Dunning's international production trade-off theory (Bao, 2015). The positive coefficient of the host country's level of trade dependence indicates that there is an obvious dependence between trade and investment; i.e., the higher the bilateral trade dependence between China and the host country is, the more likely the two countries are to have a complementary relationship in terms of trade factors, which means that the role of foreign trade in promoting direct investment will be more obvious (Markusen and Svensson et al., 1985). The negative coefficient of the geographical distance between the two countries is consistent with the research results of Zhang (2019), who suggested that when the geographical distance between two countries is too large, the cost of information exchange and other trade and investment costs between the two countries are increased; this, in turn, means that enterprises will be more inclined to choose a geographically closer country for investment when they have less capital in the early stage. However, the above findings are contrary to those of Zhang and Yong (2010), who conducted a regression analysis of panel data from the direct investment in 40 countries and regions by China using the partial least squares method, with a focus on the factors influencing host country location decisions; the authors found that the influence of the distance factor in Chinese OFDI shows a gradually decreasing trend. The positive coefficient of having a common language between the two countries indicates that when both countries speak the same language, the cost of information communication and facilitating investment negotiations is significantly reduced. The positive but low correlation coefficient of the host country' GDP indicates that China's direct investment in countries located along the route is positively correlated with the GDP of those countries; however, when economic development reaches a certain level, China prefers to invest in countries with lower levels of economic development, which is a view further argued in Ni et al. (2016). The negative and low correlation coefficient of the level of economic freedom of host countries indicates that the BRI weakens the impact of economic freedom on China's OFDI and helps enhance China's investment in regions with lower levels of economic freedom (Yao, 2019).

Empirical results of the technical inefficiency model. At the outset, it is reiterated in this section that the larger the technical inefficiency term u_{jt} is, the greater the investment losses u_{jt} and the less efficient the investment. Therefore, a positive sign of the variable under inefficiency means that the larger the value of the variable is, the greater the trade losses and the less efficient the investment.

Based on the technical inefficiency model, the regression coefficients and *t* values of each technical inefficiency variable of China's direct investment efficiency in countries and regions located along the Belt and Road route are also shown in Table 7.

Table 8 Trade efficiency values by region (%).

	2013	2014	2015	2016	2017	2018	2019
Africa	55.30	43.95	55.30	33.68	34.88	32.06	63.21
Asia	57.80	55.25	57.80	40.04	34.44	27.83	63.78
Europe	30.33	31.21	30.33	28.99	28.91	21.12	41.41
Oceania and South America	49.83	42.36	49.83	61.10	33.29	27.83	66.97
Mean efficiency: 43.39%							

The details in trade efficiency values for each country and region can be found in Supplementary Table S1 online.

In the investment inefficiency term, the regression results of the model are nearly the same as expected.

The coefficients of civil discourse with government accountability, government efficiency, and regulatory quality are negative as expected. This suggests that democracy, government operational efficiency, and regulatory governance all have a positive impact on China's OFDI. This is because a democratic political environment, efficient government operational efficiency and good regulatory quality are conducive to creating a free, convenient and transparent market, facilitating information disclosure and reducing the costs associated with information asymmetry. This reduces investors' investment risks and improves investment efficiency.

And the expected positive coefficients of political stability, legal rules and corruption in the business environment suggest that these factors in host countries does not hinder Chinese investment in countries along the route. Favorable policies such as risk guarantees, financial subsidies and tax incentives given by the Chinese government to enterprises investing along the route have largely reduced their demands on the political environment of the host country. This is also a positive effect of the Belt and Road Initiative.

Analysis of direct investment efficiency. Efficiency reflects the deviation of the actual value of OFDI from the frontier value; the smaller the efficiency, the larger the difference is between the actual value and the frontier value. In the above model, 47 countries located throughout each continent, 8 core variables and 6 technical inefficiency terms are selected to derive the efficiency of China's OFDI in countries located along the Belt and Road.

The results in Table 8 and Fig. 1 reflect the average trade efficiency value for each region, respectively. As shown in Table 8, from the overall perspective, the overall efficiency of China's OFDI in countries located along the Belt and Road is low, with an average value of 43.39%. The efficiency value fluctuated considerably in some years, especially in 2017 and 2018, showing a sharp decline. This may be due to the high-risk environment in the markets along the route, which has led to a slowdown in outward investment as a result of tight capital controls. In addition, another reason for the decline in the efficiency of China's OFDI in countries along the Belt and Road in 2018 could be the instability of global investment policies, the rise of trade protectionism, and the stricter scrutiny of foreign investment access by major foreign-investment-absorbing countries, which has shut out some large-scale mergers and acquisitions (M&A) projects.

In 2019, the efficiency of China's investment in countries along the route rebounded. This may be due to the effectiveness of the previous standardization constraints, and the compliance risk of overseas operations has been significantly improved. As Chinese enterprises continue to increase their competitiveness and influence and as the Chinese government continues to promote the "going out" policy, accelerate major economic and trade

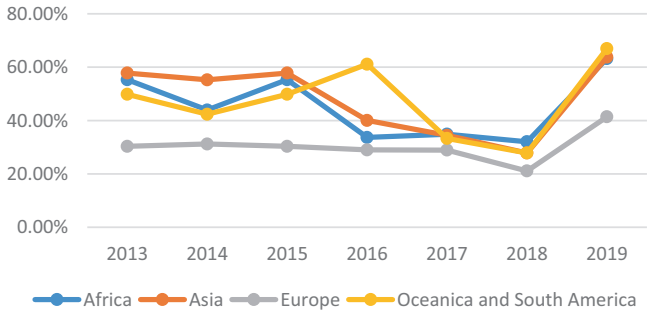

Fig. 1 Trade efficiency changes by region.

negotiations, and improve the policy support system, it is expected that the efficiency of China's investment in countries along the Belt and Road will be further improved in the future. In short, there is still an enormous potential for China's direct investment in the countries along the "Belt and Road" to develop.

In addition, as shown in Table 8 and Fig. 1, the efficiency distribution of China's OFDI to various regions is obviously uneven. The efficiency of investment in Asia and Africa is high, basically located above the efficiency average, while the efficiency of investment in Europe is far below the overall average. This may be because Africa has more mineral resources and agricultural land than the European region. China's OFDI in Africa not only helps China obtain resource support but also helps African countries introduce capital and technology, thus realizing a win-win situation. The higher efficiency of investment in Asia is mainly because China is more similar to other Asian countries in terms of geography and political environment. The cost of market development is relatively low, and it is easy to anticipate possible market risks in advance, thus enhancing the efficiency of trade and investment.

Furthermore, South America and Oceania are combined into a single disaggregated sample due to the small number of values in the 47-country sample. The efficiency value of China's direct investment in South America and Oceania fluctuates considerably from year to year, with an average efficiency value of 47%, which is basically the same as the efficiency of investment in Asia and Africa. Finally, in terms of the magnitude of fluctuation, the fluctuation of China's OFDI efficiency in Asia, Africa, South America, and Oceania is basically the same, while there is a deviation in Europe, which basically verifies the explanation of the possible causes mentioned above.

Conclusions and suggestions

Conclusions. In this study, we use the SFA model and technical inefficiency model with time-varying factors and Frontier 4.1 econometric software to regress economic variables and macro-technical inefficiency factors from 47 countries and regions located along the Belt and Road route during the period of

2013–2019 to study China's outward foreign direct investment. The following conclusions are drawn.

First, among the explanatory variables selected by the time-varying stochastic frontier gravity model that affect the absolute level of China's OFDI efficiency in countries located along the route, the technology level of the countries located along the route and whether the two countries have signed bilateral investment agreements are not significant. Furthermore, China's GDP, the host country's level of trade dependence, whether the two countries share a common language, the host country's GDP, and China's OFDI in the Belt and Road route are also not significant. China's GDP, the host country's level of trade dependence, whether the two countries share a common language, the host country's GDP, and China's efficiency level of direct investment in countries and regions located along the Belt and Road route are positively correlated, but the influence shows a decreasing trend. The host country's level of economic freedom is negatively correlated with the geographical distance and efficiency level of the direct investment between the two countries. Among all the related variables, the largest value of China's GDP coefficient indicates that the larger the size of China's economy is, the more practical its outward direct investment is, which provides an important guarantee for improving the efficiency of outward direct investment and trade.

Second, among the indicators interfering with the trade efficiency of China's OFDI in countries and regions along the Belt and Road route, the host country's legal rules are less significant, but their impact should not be underestimated. Civic discourse power, government accountability, government efficiency, and regulatory quality can all effectively improve trade efficiency. While political stability does not hinder Chinese investment in countries along the routes, the degree of control over corruption in the countries along the routes may even have a negative effect on Chinese OFDI. The Chinese government often gives more incentives to multinational enterprises, which to some extent, increases their ability to counter political risks. In addition, corruption can also have a lubricating effect on investment deals, helping to create more rent-seeking space for firms and making it less difficult for multinational firms to explore the host market. This is consistent with Buckley et al.'s (2009) opinion that firms from China perform better in environments with poorer institutions than in those with better institutions.

Third, in terms of efficiency results, the overall efficiency of China's investment in countries located along the Belt and Road is low, with a mean value of 43.39%, suggesting that there is much room for improvement. By region, China's investment efficiency in European countries is lower than that in Asia and Africa, which indicates that China may prefer to invest in environments with lower economic development than its own because, in doing so, China may obtain inexpensive labor and richer natural resources while promoting local employment development and forming a demonstration effect.

Suggestions. Based on the above analysis, the following suggestions for the Chinese government, enterprises, and countries located along the route are proposed.

For the Chinese government. First, governments should continue to promote the implementation of the BRI. The economic achievements of the BRI are obvious to all and not only drive the rapid economic development of countries located along the route but also exert a positive demonstration effect on the OFDI of Chinese enterprises in countries located along the route. The 14th Five-Year Plan of the Party proposes to comprehensively improve the level of opening up to the outside world and promote both the liberalization and facilitation of trade and investment and the high-quality development of the BRI. Therefore, the Chinese government should continue to promote the implementation of the BRI, drive the economic growth of China and the countries located along the route, and help stabilize the growth of economic and trade levels to achieve mutual benefits and a win–win situation for all parties.

Second, the risk prevention and protection mechanism for OFDI by enterprises should be improved. Empirical studies have shown that Chinese enterprises are more inclined to invest in African or Asian countries with poorer business environments than in developed countries such as Europe. Moreover, compared with the rest of the world, the Belt and Road route still consists of regions with low business environments and high investment risks. Therefore, to protect the legitimate rights and interests of Chinese enterprises regarding OFDI, the Chinese government should establish and improve its risk prevention and control system in a timely manner and disclose the political and business environments of the host countries to Chinese enterprises to minimize the extra costs caused by the asymmetry of information and to provide a reference for the OFDI decision-making of Chinese enterprises.

Third, the government should provide policy and financial support for enterprises' globalization. At present, China's economy is in a period of economic transformation of industrial structure optimization. To respond to the call of "going out", the government should actively guide enterprises to go out of the country and into the world, whether in terms of capital or policy. Whether in terms of funding or policies, the government should give appropriate preference to "going out" enterprises to comply with the development trend of economic globalization.

For enterprises. First, differentiated investment strategies tailored to local conditions should be formulated. Before engaging in OFDI, an enterprise should engage in a comprehensive assessment and analysis of the advantages and disadvantages, formulate a corresponding investment strategy, and set aside sufficient reserves to fill the risk exposure. When making strategic decisions, an enterprise should fully conduct market research to seize the opportunities brought about by market improvement. In addition, to address the country-specific differences in OFDI efficiency, enterprises investing in developed countries should strive to enhance their scientific research capabilities and improve their own scientific and technological level, using this as a basis for strengthening cooperation to realize the technology spillover effect; countries with sufficient resource endowment should understand the relevant systems of the host country's resource industry and strengthen cooperation to realize a stable supply of resources.

Second, cooperation in technological innovation with enterprises in countries located along the Belt and Road should be strengthened. Scientific and technological innovation is an important guarantee for realizing China's high-quality investment in the countries located along the Belt and Road. On the one hand, Chinese enterprises should not only strengthen their core competitiveness and carry out internationalized R&D but also provide continuous power for overseas innovation; on the other hand, they should accelerate the integration and accumulation of innovative resources between China and the countries located along the Belt and Road route through mechanisms such as joint research projects, technology transfer and cooperation in development, and the exchange of talent. On the other hand, through joint research projects, technology transfer and cooperative development, talent exchange, and other mechanisms, Chinese enterprises should accelerate the integration and

accumulation of innovation resources between China and the countries located along the route and promote the establishment of more scientific research and innovation achievements to enhance the efficiency of China's OFDI and realize greater economic potential.

For countries located along the route. First, these countries should proactively promote the implementation of the BRI. Since the implementation of the BRI has attracted worldwide attention and played a positive role in boosting economic and trade cooperation between the two sides, the countries located along the route that exhibit great potential for OFDI should continue to promote the implementation of the BRI. Although the BRI was proposed by China, it is by no means the responsibility of China alone; thus, countries located along the route should actively cooperate with China and contribute to the realization of the common development of the global economy.

Second, it is important to improve the business environment and enhance core competitiveness. For the countries located along the route, China's OFDI is a development opportunity with great potential; thus, the host country should continuously enhance its own strength, improve its business environment, actively introduce high-level and new technologies, expand its financing, increase its scientific research investment, and enhance its own core competitiveness in light of the status quo of its own economic and social development. In addition, the countries located along the route should also pay attention to the utilization rate of their own resources, learn from the experience of developed countries, rationally utilize and develop new resources, enhance the trust of investing enterprises in their own institutional environment, and promote freedom of trade.

Limitations and suggestions for future studies. This study has limitations. First, considering the availability of data and the model estimation requirements, this paper constructs an investment efficiency model that includes the examination of frontier variables, namely, the level of economic development of the two countries, the geographical distance between the two countries, the level of trade dependence on China of the countries located along the route, the level of technological development of the countries located along the route, the degree of economic freedom of the countries located along the route, the two countries' language environment, bilateral trade agreements, etc. The examination of technical inefficiency used herein is mainly concerned with the World Bank Global governance indicators; however, there are many other variables that affect trade frontiers, and the indicators of the business environment are also more extensive than the variables included in the model of the current paper. It is difficult to be completely comprehensive; therefore, the possible existence of other influencing factors has not been included in the model for examination.

Second, although the inclusion of further research variables in this paper broadens the dimension of frontier and technical inefficiency to a certain extent, it also falls creates the dilemma of requiring difficult-to-obtain data. To ensure the comprehensiveness of the research data, this paper excludes some countries with serious data deficiencies from the empirical study; thus, the final sample does not include all the countries located along the Belt and Road route. Therefore, strictly speaking, the conclusions of this paper do not represent the situation of all countries located along the Belt and Road route. In addition, due to the sudden spread of the new coronavirus epidemic in 2020, the world's economic development and foreign trade suffered a heavy blow, which may have directly led to the contamination of or extreme values in the data in 2020 and the following 2 years. Due to this uncertainty, the current paper does not take this effect into account and directly sets the time series within the period of 2013–2019; thus, there is a certain degree of data lagging present in the analysis.

Third, this paper mainly studies the efficiency of China's OFDI in countries located along the Belt and Road from a macro perspective; however, it does not include the internal factors of microenterprises in the scope of the model, which weakens the referentiality of this paper's recommendations to other enterprises to a certain extent.

Data availability

The data set used in the analysis is uploaded in Excel format as a data set file. The data was collected by the researchers from the respective organization's reports or databases (published on their website) and organized for analysis.

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Note

1 List of 47 sample countries: 14 in Africa (Senegal, Rwanda, Zambia, Mozambique, Namibia, Ethiopia, Nigeria, Zimbabwe, Uganda, Togo, Madagascar, Egypt, Benin, Niger); 15 in Asia (Mongolia, Singapore, Malaysia, Cambodia, Vietnam, Pakistan, Nepal, Kuwait, Turkey, Qatar, Saudi Arabia, Azerbaijan, Georgia, Thailand, Indonesia); 10 in Europe (Austria, Poland, Czech Republic, Bulgaria, Portugal, Hungary, Ukraine, Belarus, Italy, Luxembourg); 3 in Oceania (New Zealand, Samoa, Fiji); And 5 in South America (Chile, Bolivia, Uruguay, Ecuador, Peru).

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Author contributions

Conceptualization, QG; Formal analysis, QG and WZH; Methodology, QW and QG; Supervision, QG; Writing—original draft, WZH.; Writing—review & editing, QG, QW, and WZH.

Competing interests

The authors declare no competing interests.

Informed consent

This article does not contain any studies with human participants performed by any of the authors.

Ethical approval

Ethical approval was not required as the study did not involve human participants.

Additional information

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