

The flow of industrial lifeblood: The impact of the West-to-East oil transportation project on enterprise performance of China

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ABSTRACT

Based on the West-to-East oil transmission (WEOT) project, this paper uses the time-varying difference-in-differences method to empirically explore the impact of trans-regional oil and energy transmission strategy on the production performance of enterprises. The results reveal that the WEOT project significantly improves the production performance of enterprises along the route and enhances the production performance of other enterprises in neighboring cities as well as those in the same province. From the heterogeneity perspective, the WEOT project primarily improves private enterprises, enterprises in low-energy-dependent cities, non-labor-intensive enterprises, and enterprises in non-centrally supported industries. The results of the mechanism analysis show that the oil supply strategy primarily improves firms' production performance by improving enterprise productivity and promoting enterprise agglomeration. The research findings help to clarify the mechanism of interaction between energy supply and enterprise production performance, and provide empirical support for developing countries to navigate potential risks of energy supply shortage.

1. Introduction

International oil prices have continuously fluctuated at a high level since the outbreak of the Russia–Ukraine conflict. Energy supply security has become a “Sword of Damocles” hanging over the EU. The United States has also faced a severe energy challenge in the past 50 years. Many countries have suffered from energy crises of varying degrees, which have severely affected the stability of the international energy market, undermined the stability of global production, and restricted the sustained growth of the global economy. Countries have successfully considered establishing self-sufficient energy systems to navigate the potential risk of a tight oil supply. Among all types of energy sources, petroleum is known as the “lifeblood” of modern industry as an essential energy source and raw material for industrial production, and the international energy market deeply influences China's oil energy supply. According to the BP World Energy Statistical Yearbook 2022, 70% of China's oil consumption depended on imports in 2021, and the oil imports in eastern China account for 87% of the nation's total oil imports. The main reason for this phenomenon is the “reverse distribution” of China's petroleum resources, as more than 80% of China's petroleum resources are distributed in the northeast, northwest, and northern

China, and 70% of the petroleum consumption occurs in the eastern region. Due to high costs and efficiency losses, it is challenging for the long-distance transportation of petroleum energy to fill the consumption gap in eastern China, and importing petroleum has become the optimal short-term solution for alleviating the energy supply shortage. However, considering the ongoing turbulence in the international oil market, the necessity of building a national self-supply guarantee system for petroleum energy has become increasingly apparent, and measuring the feasibility of strategic cross-regional energy transportation projects is once again on the national agenda.

In fact, China has practiced cross-regional oil dispatch since the early twenty-first century with the West-to-East oil transportation project (hereinafter, the WEOT project). The WEOT project transports rich oil resources from western China to central China through the Western Refined Oil Pipeline, the Lanzhou–Chengdu–Chongqing pipeline, and the Lanzhou–Zhengzhou–Changsha pipeline, providing oil for the areas along the route. Previous research has primarily focused on macro-level investigations of the impact of oil price fluctuation and oil resource supply on the global economy, regional economies, and industry development (Dario et al., 2019; Mohaddes and Pesaran, 2016; Herrera and Rangaraju, 2020). Little literature has explored the impact of

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implementing large-scale energy transportation strategies on firm-level production performance.

Based on micro data of industrial enterprises in China, this paper empirically explores the influence of energy supply on enterprises' production performance and its mechanism by using the time-varying difference-in-differences (DID) method. The marginal contributions of this study are threefold. First, from the perspective of China's large-scale energy transportation strategy, the study examines the microeconomic effects of the WEOT project for the first time, providing empirical support for China's response to international energy constraints. Second, it empirically concludes that implementing the WEOT project enhances the enterprise's performance through the productivity enhancement effect and enterprise clustering effect. Third, to further exert the WEOT project effect effectively to improve enterprises' production performance, this paper analyzes the influence of the WEOT project on different types of enterprises. The findings provide empirical evidence for strategically adjusting the WEOT project to advance policy effects and alleviate China's regional energy supply tensions.

The structure of the remaining sections is arranged as follows. Section 2 presents the WEOT project's background and theoretical mechanism. Section 3 details the study's experimental design. Section 4 outlines the results of the empirical test. Section 5 presents the mechanism analysis. Section 6 is further analysis, and Section 7 details the conclusions and recommendations.

2. Project background and theoretical mechanism

2.1. The background of the WEOT project

The objective reality of the mismatch between China's energy distribution and demand necessitates effective cross-regional energy dispatch strategies. In response, the Chinese government initially conceived the WEOT project strategy at the end of the twentieth century. The Lanzhou–Chengdu–Chongqing pipeline, the Western Refined Oil Pipeline, and the Lanzhou–Zhengzhou–Changsha pipeline were successively put into operation from September 2002 to November 2013, transporting oil products from Xinjiang to central China. The construction of three pipelines has greatly improved the uneven allocation of oil resources in China.

The Lan–Zheng–Chang pipeline, which is also known as the Lanzhou–Zhengzhou–Changsha pipeline, starts in Lanzhou in the west and crosses five provinces (Gansu, Shaanxi, Henan, Hubei, and Hunan). It is the most recent pipeline in the WEOT project to be constructed and placed in production and also the largest oil product pipeline in China. Among the three pipelines of the WEOT project, only the construction progress of the Lan–Zheng–Chang pipeline was promptly announced by the State-owned Assets Supervision and Administration Commission of China, which provides an official channel for obtaining relevant information. Therefore, this study mainly focuses on the microeconomic effects of implementing the WEOT project as represented by the Lan–Zheng–Chang pipeline. The Lan–Zheng–Chang pipeline has been under construction in stages since 2009. In the first stage, in March 2009, the Lanzhou–Zhengzhou section was produced, supplying eight cities of Lanzhou, Dingxi, Zhangjiachuan, Baoji, Weinan, Sanmenxia, Luoyang, and Zhengzhou with oil. In the second stage, in August 2009, the Zhengzhou–Yangluo section of the pipeline was put into operation, and connected five cities of Xuchang, Zhumadian, Xinyang, Xiaogan and Wuhan with oil. In the third stage, Yangluo–Changsha Terminal Station was operated in November 2013, supplying oil to three cities: Xianning, Yueyang, and Changsha. The trunk line of the Lan–Zheng–Chang pipeline was then completed and operational, connecting the oil-producing areas in northwest China with the finished oil consumption market in central China. Table 1 presents all stations with oil distributing functions along the Lan–Zheng–Chang pipeline.

Table 1

The location of the Lan-zheng-Chang pipeline.

Oil supply year	Main Stations	Location
2009.03	Dingxi Pressure-relief Offtake Station	Dingxi
	Zhangjiachuan Pump Station	Zhangjiachuan
	Fengxiang Offtake Valve Chamber	Baoji
	Weinan Pump Station	Weinan
	Sanmenxia Offtake Pump Station	Sanmenxia
	Luoyang Offtake Pump Station	Luoyang
2009.08	Zhengzhou Pump Station	Zhengzhou
	Xuchang Offtake Valve Chamber	Xuchang
	Xiping Pump Station	Zhumadian
	Xinyang Offtake Pump Station	Xinyang
	Xiaogan Offtake Station	Xiaogan
	Wuhan Offtake Pump Station	Wuhan
2013.11	Yangluo Offtake Valve Chamber	Wuhan
	Xianning Offtake Station	Xianning
	Changtang Offtake Valve Chamber	Changtang
	Changsha Terminal Station	Changsha

2.2. Impact of the WEOT project on regional oil supply capacity

Under the background of uneven distribution of energy supply and demand, the strong policy guidance of the Chinese government and the gradual maturity of pipeline transportation technology are two key factors for the WEOT Project to enhance the regional oil supply capacity effectively. China's oil resources have seriously uneven distribution (Zhang et al., 2012; Liu et al., 2023), and the "reverse distribution" of oil demand and supply seriously restricts China's economic and social development. Against this background, China has proposed the strategy of sending oil from the west to the east, aiming to utilize the government's macro-control ability and strengthen policy guidance to reduce the economic losses caused by the uneven distribution of energy (Chen et al., 2010). On the one hand, the strong policy guidance of the Chinese government has stimulated oil exploitation in the exporting regions and improved the oil supply capacity of the exporting regions; on the other hand, it has effectively eliminated the situation of "more in the west and less in the east" of oil resources and further improved the oil supply capacity of the importing regions of the project. At the same time, from the perspective of energy transportation mode, oil pipeline transportation of the WEOT project has huge advantages over traditional highway and railroad transportation in terms of transportation efficiency, transportation cost and safety (Green and Jackson, 2015; Guo et al., 2016). With the continuous maturity of pipeline transportation technology in design, construction, maintenance and operation, it will effectively make up for the problems of low transportation efficiency, high transportation cost and low safety of traditional oil transportation, thus enhancing the regional oil supply capacity.

2.3. Theoretical mechanism of the WEOT project affecting enterprises' production performance

The provision of adequate energy supply has always been an important issue of common concern for all countries. Previous research regarding energy issues has primarily focused on the rational allocation and effective supply of energy due to energy limitations and the non-renewable nature of most energy sources. Energy supply is often disrupted by various natural and human factors, such as "reverse distribution" (Zhang et al., 2012) and long-distance energy transportation loss (Zhang et al., 2018). Adequate energy supply can effectively promote regional economic growth (Ghosh, 2009), and government regulation and intervention can also guide the direction of energy supply and energy industry development. Acemoglu et al. (2016) introduced non-renewable and clean energy into an endogenous growth model, analyzing the impact of environmental regulation policies on the promotion of clean energy, and determined that tax or subsidy policies can guide technological innovation to increase the input of clean factors.

Based on the above theoretical and practical background, this section incorporates the large-scale energy transportation strategy into the development economics research framework, and explores the influence of WEOT project implementation on micro-subjects' production performance and its mechanism.

2.3.1. The improvement effect of productivity

Early literature on enterprise productivity primarily focused on the impact of traditional production factors such as capital, technology, and labor on enterprise productivity (Crespi and Zuniga, 2012; Parrotta et al., 2014). In recent years, some research has begun to incorporate energy factors into the measurement framework for enterprise productivity, demonstrating that the rational allocation of energy is often affected by various natural or human factors (Asif and Muneer, 2007; Zhao et al., 2013). A stable and reliable energy supply can effectively promote regional productivity improvement (Grainger and Zhang, 2019). Fingleton-Smith (2020) determined that the biggest advantage of modern energy is its ability to increase productivity, while insufficient energy supply will lead to a decrease in enterprise productivity (Elliott et al., 2021).

Three main reasons are attributable to the decline in productivity that is caused by the insufficient supply of petroleum energy. First, petroleum shortage will directly lead to a shortage of raw materials for enterprises that use petroleum or its derivatives as main raw materials (Maul, 1984), and can even stop production, seriously reducing enterprises' productivity. Second, insufficient energy supply will cause enterprises to reduce the amount of equipment running, making fixed assets and operators idle, which will lead to insufficient industrial production power and reduce enterprises' production (Obokoh and Goldman, 2016). Most machinery and equipment in industrial production cannot operate without the power provided by petroleum derivatives; therefore, insufficient oil supply will inevitably lead to insufficient production power and decreased output. Third, inadequate energy supply inhibits the ability to place the factors of production fully into production, decreasing the utilization efficiency of various factors of production and causing a loss of production efficiency (Falentina and Resosudarmo, 2019). Insufficient oil supply reduces the input-output efficiency of machinery purchases and maintenance, capital and labor wages, and lowers enterprises' production performance.

In summary, the insufficient supply of petroleum energy will seriously damage enterprises' productivity, and the WEOT implementation can improve production efficiency by effectively alleviating the constraints of oil energy, ultimately promoting optimal production performance.

2.3.2. The agglomeration effect of enterprise

Since the introduction of "New Economic Geography" (Krugman, 1992), the causes and economic benefits of business agglomeration have attracted the attention and research of a large number of scholars worldwide (Gaubert, 2018; Ellison et al., 2010). Existing studies mainly focus on the induced effects of infrastructure development, such as transportation and networks, on business agglomeration (Zeng et al., 2019; Ahlfeldt and Feddersen, 2018). Liu et al. (2022) analyzed the effects of infrastructure development on business agglomeration in developing countries from China's highway construction perspective. They found that transportation infrastructure promotes business agglomeration, and this effect is mainly realized by promoting the free flow of factors between regions (Lee et al., 2012). As China's large-scale energy delivery strategy, developing oil transportation infrastructure can improve the free flow of oil resources between regions, increase the availability of regional oil energy, and attract enterprise agglomeration.

Enterprise agglomeration can improve enterprise production performance effectively (Lin et al., 2011; Yuan et al., 2020). First, according to Schumpeter's view of "creative destruction", the agglomeration effect brought about by the entry of enterprises will break the original economic equilibrium and form a new competitive mechanism (Koellinger,

2008). The new mechanism will improve the production performance of enterprises by accelerating the elimination of backward enterprises and incentivizing enterprise innovation. Second, enterprise agglomeration will pull the geographic distance between enterprises and effectively promote the free flow of factors such as labor and capital (Xie et al., 2021). The concentration of talent due to enterprise agglomeration reduces the extra cost incurred by enterprises in searching for suitable labor, and improves the matching efficiency between job supply and labor, which in turn enhances the economic performance of enterprises. Third, enterprise agglomeration is more likely to form inter-firm knowledge spillover effects, forming positive externalities, promoting the free dissemination of R&D and design, marketing and organizational management and other types of production and management knowledge among enterprises, and ultimately enhance the economic performance of enterprises. The research framework is shown in Fig. 1.

Based on the above theoretical analysis, this paper proposes the following research hypotheses:

Hypothesis 1. Implementing the WEOT project can improve firms' production performance.

Hypothesis 2. Implementing the WEOT project enhances firms' production performance mainly by improving productivity and firm agglomeration effects.

3. Research design

3.1. Model setting

The DID method is widely used to evaluate policy effects. As China's key energy transportation strategy, the WEOT project has the characteristic of opening in specific waves, providing a perfect quasi-natural experiment condition for constructing a DID model. Referencing Wang et al. (2023), this study constructs a time-varying DID method to empirically test the impact of the WEOT project on enterprises' production performance. The specific model is set as follows:

$$performance_{i,c,t} = \alpha + \alpha_1 did_{i,c,t} + \beta X_{i,t} + \gamma X_{c,t} + \mu_i + \sigma_t + \varepsilon_{i,t} \quad (1)$$

where subscripts i , c , and t denote enterprise, city, and year, respectively, and the explanatory variable $performance_{i,c,t}$ represents enterprises' production performance. The $did_{i,c,t}$ indicates the core explanatory variable, wherein if city c , where enterprise i is located, implements the WEOT strategy, then the value is 1, otherwise the value is 0. X is a collection of control variables, including firm- ($X_{i,t}$) and city-level ($X_{c,t}$) control variables. μ_i and γ_t denote firm and year fixed effects, respectively, and $\varepsilon_{i,t}$ is the random error term. In this model, we focus on the coefficient α_1 for which a significantly positive indication, means that the WEOT project effectively improved firms' performance.

3.2. Variable selection and construction

Explained variables. Firm production performance ($performance$), referencing Bernard et al. (2019), is characterized by gross enterprise industrial output value per capita ($performance1$) and firm product sales revenue per capita ($performance2$).

Core explanatory variables. WEOT project implementation (did) is a dummy variable, taking the value of 1 if the city c to which enterprise i belongs receives oil shipped from the WEOT project in year t and 0 otherwise. Notably, if a city is supplied with oil in July and thereafter, the following year is considered the year in which the project occurred.

Control variables. In this paper, the factors that may affect the production performance of enterprises are selected as control variables from the enterprise level and city level as follows:

Enterprise level: The age of the enterprise ($lnage$), characterized by the actual year minus the year of the enterprise's establishment plus one logarithmically. With the increasing years of the enterprise, production

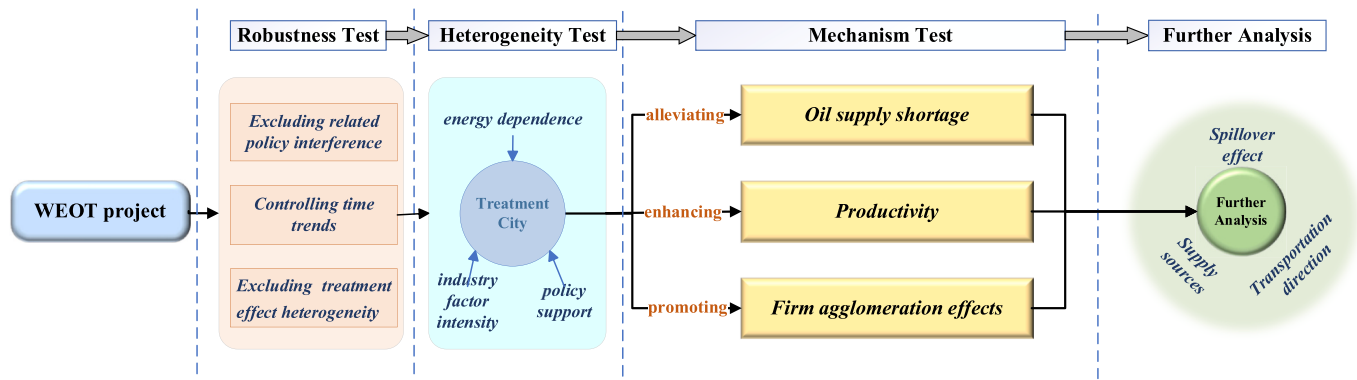


Fig. 1. Research framework.

factors, production experience and organization and management capabilities continue to accumulate, which will further enhance the production performance of the enterprise; enterprise asset liquidity (liqu), we characterize it using current assets as a share of total assets. The higher the liquidity of enterprise assets, the more effective to avoid capital chain and production interruption and other problems, to ensure the stability of production, and thus improve the production performance of the enterprise; real leverage (levv), we use the proportion of total liabilities to the total assets of the enterprise to characterize it. Higher corporate liabilities may increase the interest burden, debt servicing pressure, and reduce liquidity, which will lead to credit rating downgrades and a shift in business focus, thus affecting corporate production performance; corporate export level (expor), we use corporate exports as a proportion of total assets to characterize it. Enterprises with higher levels of exports can effectively expand their international markets, and an increase in the market size will in turn effectively stimulate production.

City level: the level of economic development (gdp), measured by the city's total GDP (logarithmic) (Topalova and Khandelwal, 2011); population (pop), measured by the population of the regional city (logarithmic); and the industrial structure index (ols), measured by the proportion of the value added of the tertiary sector in relation to the value-added of the secondary sector in the city. The basis for selecting the above macro-control variables is that the higher the level of urban economic development, the more concentrated the population, and the more advanced the industrial structure, the more favorable the endowment of talent, capital, technology and other factors in the region, which can provide sufficient factor support for the production of enterprises, and thus improve the production performance of the enterprises in the region. The descriptive statistics of relevant variables are shown in Table 2.

3.3. Data sources and stylized facts

The data of this paper comes from four databases, including the

Table 2
Descriptive statistics.

Variable	Observations	Mean	Sd	Min	Max
Firm-level					
performance1	2,435,424	5.868	1.036	3.216	9.561
performance2	2,435,474	5.836	1.035	3.131	9.538
lnage	2,489,600	2.014	0.739	0.000	4.007
liqu	2,460,953	0.434	0.166	0.021	0.723
levv	2,470,196	0.414	0.190	0.002	1.012
expor	2,035,023	0.159	0.367	0.000	2.122
City-level					
gdp	2243	10.185	0.7362	4.595	13.056
ols	2243	0.791	0.3968	0.094	3.758
pop	2243	5.852	0.6931	2.868	8.124

China Industrial Enterprise Database, the China Tax Survey Database, the TianYanCha Platform, and the China City Statistical Yearbook. Specifically, data for enterprise production performance and enterprise-level control variables are obtained from the China Industrial Enterprise Database, which is compiled by the National Bureau of Statistics and contains annual data on all state-owned and above-scale non-state-owned industrial enterprises. We select a sample from 2006 to 2014 and reference Brandt et al. (2012), processing the data as follows: We exclude observations with missing key indicators (e.g., total assets, gross industrial output value, number of employees, sales, and net fixed assets). We then exclude observations for which total assets are smaller than current assets, total assets are smaller than fixed assets, accumulated depreciation is smaller than current depreciation, and continuous variables are winsorized by 1%. The oil consumption data are obtained from the National Enterprise Tax Survey database. The data on enterprise concentration are obtained from the TianYanCha Platform, which contains information related to all enterprises registered in China's industry and commerce, including enterprises' detailed addresses, names, industry classifications, year of registration, and enterprise type. This study takes the year of registration as the year of enterprises' entry, manually calculates the enterprise entry data at the city-year level according to enterprises' addresses, and obtains the balanced panel data at the city level from 2006 to 2014, predominantly used for mechanism testing. And city-level control variables, such as GDP and total population, are obtained from the China Urban Statistical Yearbook.

Before the regression, this study plots the annual average changes in enterprises' production performance in pipeline-connected and non-pipeline-connected cities before and after the WEOT project implementation, as shown in Fig. 2. Before the Lan-Zheng-Chang pipeline was constructed, the annual average production performance of the treatment and control groups was the same. However, after the WEOT project implementation, the production performance of enterprises affected by the WEOT project significantly improved compared with those unaffected by the project. Based on this characteristic fact, this study reasonably predicts that the WEOT strategy has effectively improved the production performance of enterprises in WEOT-connected cities.

4. Empirical test

4.1. Baseline regression

We use Eq. (1) to test the impact of the WEOT strategy on firm production performance. The regression results are shown in Table 3, which shows that the WEOT project significantly increases enterprises' gross industrial output value and product sales revenue at the 1% significance level, regardless of whether control variables are included. On average, implementing the WEOT project increased enterprises' per capita gross industrial output value and per capita product sales revenue

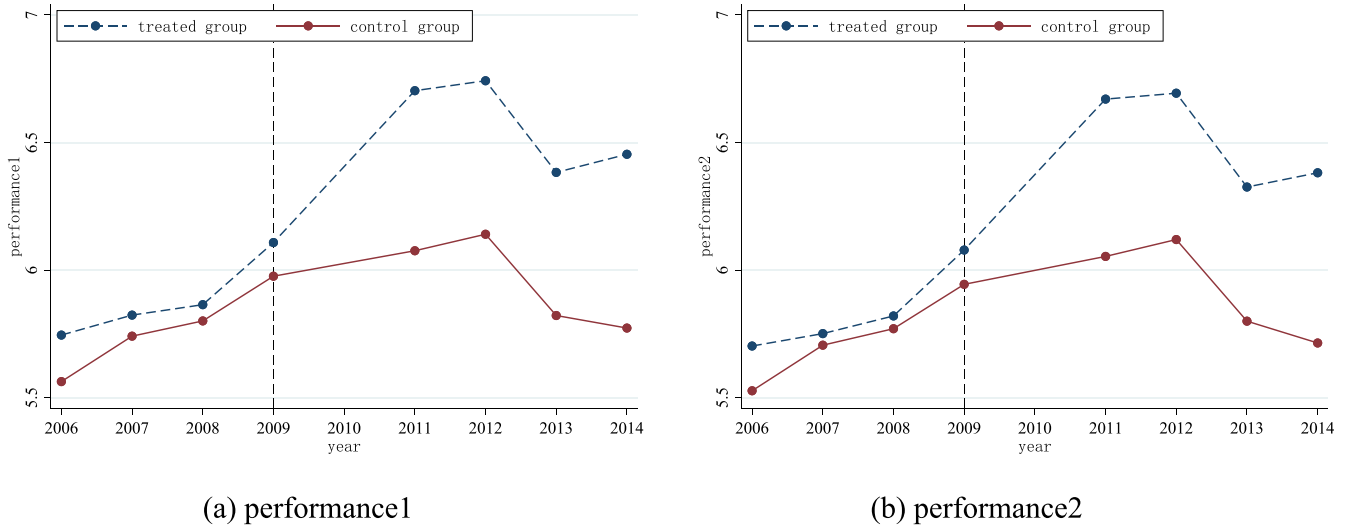


Fig. 2. The trends of production performance.

Table 3
Baseline regression.

Variables	(1) performance1	(2) performance1	(3) performance1	(4) performance2	(5) performance2	(6) performance2
did	0.2299*** (0.037)	0.1795*** (0.043)	0.1074*** (0.035)	0.2192*** (0.034)	0.1795*** (0.042)	0.1070*** (0.035)
lnage		0.1955*** (0.010)	0.1743*** (0.010)		0.2128*** (0.010)	0.1913*** (0.010)
liqu		-0.1208*** (0.022)	-0.1059*** (0.024)		-0.0048 (0.020)	0.0114 (0.020)
levv		-0.1149*** (0.017)	-0.1041*** (0.017)		-0.1738*** (0.014)	-0.1632*** (0.013)
expor		0.2051*** (0.007)	0.2017*** (0.007)		0.2064*** (0.007)	0.2029*** (0.007)
gdp			0.1185*** (0.032)			0.1247*** (0.034)
ols			-0.7456*** (0.053)			-0.7459*** (0.053)
pop			0.0923 (0.065)			0.0860 (0.063)
Constant	5.8833*** (0.005)	5.5082*** (0.021)	4.3739*** (0.500)	5.8548*** (0.005)	5.4171*** (0.021)	4.2542*** (0.508)
Year FEs	Yes	Yes	Yes	Yes	Yes	Yes
Firm FEs	Yes	Yes	Yes	Yes	Yes	Yes
N	2,033,194	1,647,253	1,629,402	2,037,799	1,651,422	1,633,535
R ²	0.765	0.785	0.788	0.766	0.787	0.790

Note: ***, **, and * denote 1%, 5%, and 10% significance levels, respectively; standard errors in parentheses are clustered at the city-year level.

by 10.74% and 10.70%, respectively, confirming Hypothesis 1.

In addition, the results of the control variables in columns (3) and (6) show that the age of enterprises, the export level of enterprises, and the level of economic development have significantly positive effects on production performance. However, the debt ratio of enterprises and the upgrading of the regional industrial structure have a significant negative effect on the production performance of enterprises, and the liquidity of the assets of enterprises and the concentration of the city's population have no significant impact on the production performance of enterprises. The above conclusions are consistent with the economic phenomenon. It should be explained that the upgrading of regional industrial structure reduces the production performance of enterprises because our industrial structure index is measured by the ratio of the output value of the tertiary industry to the output value of the secondary industry; the higher the production performance of the enterprises, the higher the output value of the secondary industry corresponds to it, and the lower the index of the industrial structure is, which is the reason why

the index of industrial structure has a significant negative correlation with the production performance of enterprises. The results of the above control variables further verify the rationality of the selection of control variables and the authenticity and reliability of the data in this paper.

4.2. Parallel trend test

We next test whether the sample for the baseline regression satisfies the parallel trend assumption. This study references Deschenes et al. (2017), constructing the following econometric model:

$$performance_{i,c,t} = \beta_0 + \sum_{k=-8}^{k=5} \beta_k did_{c,t}^k + \beta_x X_{i,t} + \gamma X_{c,t} + \mu_i + \sigma_t + \varepsilon_{i,t} \quad (2)$$

where β_k captures the differences between treatment and control group firms before and after the WEOT strategy implementation. We select the period before WEOT strategy implementation (t-1) as the base period, and the subscript k represents the number of periods that differ from the

base period. Other variables are the same as Eq. (1). The results in Fig. 3 indicate that there is no significant difference between the production performance of enterprises in the treated and control groups prior to WEOT strategy implementation, indicating that Eq. (1) satisfies the parallel trend test. In the first period following WEOT strategy implementation (year = t), the treated group's production performance is positive but not significant, and over time, the treatment group enterprises' performance is significantly higher than that of the control group, indicating that WEOT strategy implementation has effectively improved production performance, with the characteristic of sustainable growth.

4.3. Robustness tests

4.3.1. Excluding the interference of related policy

To alleviate energy distribution conflicts, China has also implemented other cross-regional energy transmission projects, such as the West-East Gas Transmission Strategy and the West-East Electricity Transmission Strategy. As initiatives to address energy supply challenges during the same period, these projects may also impact firms' production performance. The following robustness tests are conducted to exclude the interference of such projects on the experimental results.

First, we exclude the interference of the Lan-Cheng-Yu pipeline, which passes through four cities (Gansu, Shanxi, Sichuan, and Chongqing) and is one of the pipelines of the WEOT project. Considering the possible economic effects of the Lan-Cheng-Yu pipeline on enterprises along its route, enterprises in prefecture-level cities where Lanzhou-Chengdu-Chongqing pipeline offtake stations are located are excluded from the sample based on the benchmark regression.

Second, we exclude interference from the West-to-East gas transmission project. The first line of the West-to-East gas transmission project supplies gas to Henan, Anhui, Jiangsu, Zhejiang, Shanghai, and Shanxi provinces, transporting the abundant natural gas resources from western to eastern of China. Samples from Henan, Anhui, Jiangsu, Zhejiang, and Guangdong provinces in the period from 2010 to 2014, which received larger amounts of natural gas from the West-to-East gas transmission project, are excluded.

Finally, we exclude the interference of the West-to-East electricity transmission project, which contains northern, middle, and southern lines. Considering that the sample years of this paper are from 2006 to 2014, the provinces that were connected to the transmission line during this period (i.e., Gansu, which was connected to the northern line in 2008; Liaoning, which was connected to the northern line in 2009; and Hainan, which was connected to the southern line in 2010) are excluded.

Table 4 presents the regression results, which shows that the baseline results in Table 3 are robust.

4.3.2. Controlling time trends

In principle, the DID model allows for a non-time-varying selection bias in sample selection (i.e., the DID model only requires that the treated and control groups maintain the same trend of change when there is no project implementation and does not strictly require that they are identical prior to the project shock); thus, the parallel trend test in this study is essentially an ex-ante trend test. However, when relevant control variables affecting the firm's production performance are also subjected to project shocks following project implementation, the ex-ante trend maintained before the project is bound to be disrupted; thus, the average trend assumption is not valid. In order to avoid the sample selection bias problem brought about by such time-varying factors, this paper further refers to the relevant research practices of Lin et al. (2023) to construct the interaction terms of the control variables with the time dummy variables as well as the interaction terms of the control variables and the time polynomials, respectively, and add them to the baseline model for the baseline regression, which is constructed as follows:

$$\text{performance}_{i,c,t} = \alpha + \beta_1 \text{did}_{i,c,t} + \beta_x X_{i,t} + U_i(X_{i,t} \times \sigma_t) + \mu_i + \sigma_t + \varepsilon_{i,t} \quad (3)$$

$$\text{performance}_{i,c,t} = \alpha + \beta_1 \text{did}_{i,c,t} + \beta_x X_{i,t} + D_t(X_{i,t} \times f(T)) + \mu_i + \sigma_t + \varepsilon_{i,t} \quad (4)$$

The regression results based on the above model are shown in Table 5. The results of columns (1) to (2) are added to the interaction terms of control variables and year dummy variables, and columns (3) to (4) are added to the interaction terms of control variables and the third-order polynomials of year dummy variables. After controlling the interaction terms of year and control variables, the results show that the regression results for WEOT strategy implementation on enterprises' production performance remain significantly positive at the 1% level, further verifying the robustness of the baseline regression results.

4.3.3. Exclude heterogeneous treatment effects

With the widespread use of the time-varying DID method, some econometric theoretic economists have pointed out that there is an estimation bias in identifying the average treatment effect of policies using the traditional TWFE statistic (Callaway and Sant'Anna, 2021). This bias stems from two main components, one of which is that the traditional TWFE estimator to obtain the average treatment effect of the time-varying DID method is a weighted average of the three types of DID

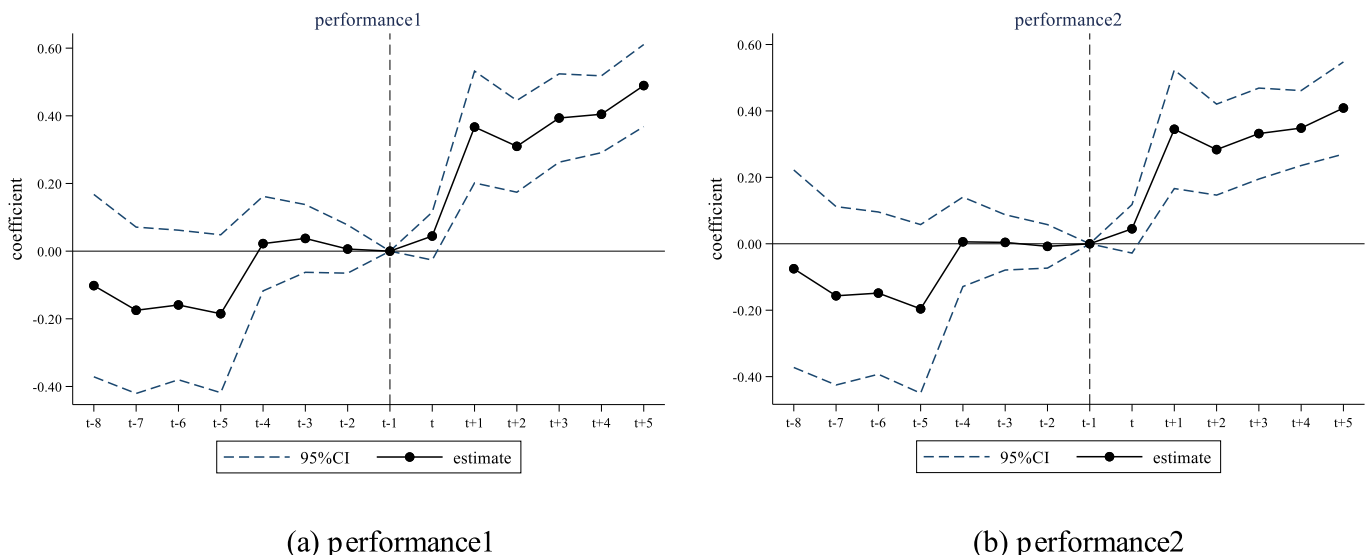


Fig. 3. The parallel trend.

Table 4
Robustness test: Excluding interference from other energy transportation policy.

Variables	(1)		(2)		(3)		(4)		(5)		(6)	
	Exclude the Lan-Cheng-Yu pipeline				Exclude the West-to-East gas transmission project				Exclude the West-to-East electricity transmission project			
	performance1		performance2		performance1		performance2		performance1		performance2	
did	0.1113*** (0.037)	0.1141*** (0.038)	0.1074*** (0.035)	0.1070*** (0.035)	0.1092*** (0.035)	0.1082*** (0.036)						
Constant	4.4712*** (0.491)	4.3459*** (0.502)	4.3739*** (0.500)	4.2542*** (0.508)	3.5205*** (0.759)	3.2555*** (0.775)						
Control variables	Yes	Yes	Yes	Yes	Yes	Yes						
Year FEs	Yes	Yes	Yes	Yes	Yes	Yes						
Firm FEs	Yes	Yes	Yes	Yes	Yes	Yes						
N	1,561,703	1,565,644	1,629,402	1,633,535	1,374,375	1,377,522						
R ²	0.788	0.790	0.787	0.789	0.788	0.790						

Note: ***, **, and * denote 1%, 5%, and 10% significance levels, respectively; standard errors in parentheses are clustered at the city-year level.

Table 5
Robustness testing: controlling for time trends.

Variables	(1)		(2)		(3)		(4)	
	The year dummy variables				The third-order polynomials of year dummy variables			
	performance1		performance2		performance1		performance2	
did	0.0874*** (0.032)	0.0841*** (0.032)	0.0972*** (0.031)	0.0941*** (0.031)				
Constant	3.1968*** (0.564)	3.0067*** (0.563)	3.7928*** (0.460)	3.6290*** (0.449)				
Control variables	Yes	Yes	Yes	Yes				
Year FEs	Yes	Yes	Yes	Yes				
Firm FEs	Yes	Yes	Yes	Yes				
N	1,629,402	1,633,535	1,629,402	1,633,535				
R ²	0.792	0.794	0.791	0.793				

Note: ***, **, and * denote 1%, 5%, and 10% significance levels, respectively; standard errors in parentheses are clustered at the city-year level.

treatment effects (Goodman-Bacon, 2021), and according to the algorithmic principle of TWFE, there is a possibility that some of the weights are negative, which implies that even if the policy effect is positive at every point in time, the treatment effect obtained from the final weighting may be negative (De Chaisemartin and d’Haultfoeuille, 2020). Another is that “newly treated individuals vs. already treated

individuals” included in the three types of treatment effects weighted is a “bad” treatment effect. When there is heterogeneity in the treatment effects of the policy on each individual, the average treatment effect obtained from the TWFE estimation may be partially mixed with the dynamic treatment effect, leading to estimation bias (Goodman-Bacon, 2021).

The main source of this bias stems from using first-treated individuals as a control group for treated individuals. In response to this problem, many econometricians have proposed a series of robust estimators of heterogeneity that exclude the aforementioned groupings. Therefore, this section uses the S-A statistic (Sun and Abraham, 2021) to re-estimate the benchmark results in order to increase the reliability of the empirical results. The results are shown in Fig. 4, where dynamic effects consistent with the ex-ante trend can be obtained after the estimation of the S-A statistic to rule out the problem of heterogeneity of treatment effects, which further validates the robustness of the conclusions of this paper.

4.3.4. Additional robustness tests

Excluding special cities: Municipalities directly under the central government, provincial capitals and sub-provincial cities are national-level administrative districts and separately listed cities under the direct jurisdiction of the central government, having a special administrative status and comparative advantages over other cities in terms of politics, economy, culture, policies, science and technology,

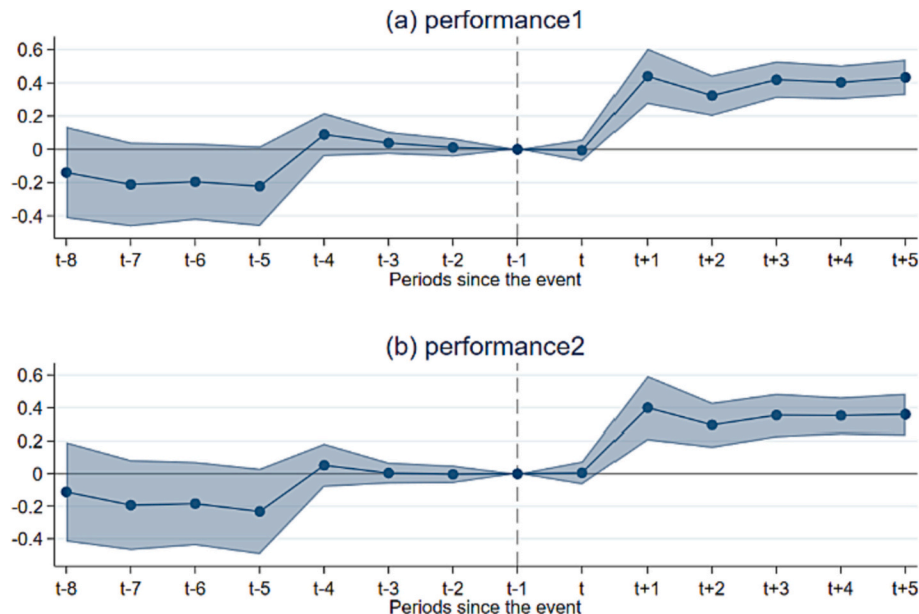


Fig. 4. Dynamic effects that exclude heterogeneous treatment effects.

transportation and even energy supply, etc. Considering the special characteristics of the samples of municipalities, provincial capitals, and sub-provincial cities, this part of the sample is excluded in this section.¹ The regression results are shown in columns (1)–(2) of Table 6.

Controlling the industry-year fixed effects: To avoid non-observable time-varying confounding factors at the industry level from interfering with the effective identification of the model, this paper further conducts robustness tests by controlling for industry-year fixed effects. The empirical results in Table 6 show that after excluding the interference of special economic regions and controlling for industry-year effects on the empirical results, the WEOT Project still significantly improves firms' production performance, further verifying the robustness of the benchmark results.

4.4. Heterogeneity test

4.4.1. Heterogeneity effect of business ownership

Unlike non-state enterprises, local governments have a resource-tilting effect on state-owned enterprises (SOEs), including collective enterprises. Important industries and key areas that represent the lifeblood of the national economy are often dominated by SOEs. Because of the natural link between SOEs and local governments, local governments tend to allocate more resources to SOEs in many ways, including financial disincentives, tax breaks, and market monopolies (Liang et al., 2012). In contrast to SOEs, non-SOEs face greater market competition and survival pressure due to the nature of their ownership and equity structure, such as financial discrimination and external financing constraints (Hasan et al., 2014). Therefore, we argue that due to the limited oil resources before implementing the WEOT project, the government prioritized SOEs to ensure stable supply, resulting in long-term unmet oil demand for non-SOEs that prevented them from fully developing production. Following the WEOT project implementation, non-SOEs' production performance will be enhanced more significantly as the oil demand of non-SOEs can be met due to the sufficient supply of oil resources.

Table 6
Other robustness tests.

Variables	(1)	(2)	(3)	(4)
	Excluding special cities		Control industry-year fixed effect	
	performance1	performance2	performance1	performance2
did	0.1313*** (0.047)	0.1483*** (0.048)	0.0972** (0.038)	0.0952** (0.038)
Constant	5.5083*** (0.021)	4.3741*** (0.500)	5.4171*** (0.021)	4.2544*** (0.508)
Control variables	Yes	Yes	Yes	Yes
Year FEs	Yes	Yes	Yes	Yes
Firm FEs	Yes	Yes	Yes	Yes
Ind-year FEs	No	No	Yes	Yes
N	1,102,271	1,104,298	1,519,334	1,523,083
R ²	0.786	0.787	0.786	0.788

Note: ***, **, * denote 1%, 5%, and 10% significance levels, respectively; standard errors in parentheses are clustered at the city-year level.

¹ Municipalities include: Beijing, Shanghai, Tianjin, Chongqing. Provincial capitals include: Beijing, Shanghai, Tianjin, Chongqing, Lanzhou, Xining, Xi'an, Zhengzhou, Jinan, Taiyuan, Hefei, Changsha, Wuhan, Nanjing, Chengdu, Guiyang, Kunming, Harbin, Changchun, Shenyang, Shijiazhuang, Hangzhou, Nanchang, Guangzhou, Fuzhou, Haikou, Nanning, Lhasa, Yinchuan, Urumqi, Hohhot. Sub-provincial cities including: Tianjin, Chongqing, Ningbo, Qingdao, Dalian, Xiamen, Anyang, Changzhou, Xi'an, Fuzhou, Wuxi. Planned cities including: Dalian, Qingdao, Ningbo, Xiamen.

The regression results are shown in Table 7. Columns (1)–(2) present the regression results of the WEOT strategy on the gross industrial output value of SOEs and non-SOEs, respectively, and columns (3)–(4) present the regression results of the WEOT strategy on the product sales revenue of SOEs and non-SOEs, respectively. With or without the inclusion of control variables, the coefficients and significance of *did*nonsoe* are generally higher than those of *did*soe*. This result suggests that the WEOT project has a stronger effect on the economic efficiency of non-SOEs than that of SOEs. The reason may be that prior to the WEOT project implementation, SOEs were relatively well supplied with energy based on their special economic status. They were less constrained by energy supply than non-SOEs, and the effect of WEOT project implementation on SOEs was relatively smaller. The WEOT project predominantly alleviated the energy constraints of non-SOEs that were previously severely undersupplied with energy, and therefore effectively improved the production performance of non-SOEs.

4.4.2. Heterogeneity of energy dependence

Differences in the energy endowments of cities where enterprises are located may lead to different levels of energy dependence. Compared with higher energy-dependence cities, those with lower energy dependence have more opportunity to use energy to develop related industries and are more vulnerable to the impact of the WEOT project. This study divides the sample into high- and low-energy-dependent cities based on the median oil consumption intensity of each province in the year before the project (2008). The specific measure of oil consumption intensity by province is the sum of crude oil, gasoline, kerosene, diesel, and fuel oil consumption by province divided by the GDP of each province in that year, and the energy consumption data are obtained from the China Energy Statistical Yearbook. Table 8 reports the effect of the WEOT strategy on the production performance of enterprises located in cities with different levels of energy dependence, where *led* represents cities with low energy dependence, and *did*low* identifies cities with low energy dependence, and *did*high* identifies cities with high energy dependence. The empirical results demonstrate that the estimated coefficients of *did*low* are significantly higher than that of *did*high*, indicating that WEOT project implementation predominantly alleviates the energy constraints of firms in cities with low energy dependency and effectively improves the production performance of firms in such cities, while the project does not significantly affect the production performance of enterprises in cities with high-energy dependency.

4.4.3. Heterogeneity of industry

As a large energy transportation strategy, the WEOT project requires

Table 7
Heterogeneity test: Firm ownership.

Variables	(1)	(2)	(3)	(4)
	performance1	performance2	performance1	performance2
did*soe	0.1525** (0.061)	0.0792 (0.054)	0.1520*** (0.056)	0.0779 (0.049)
did*nonsoe	0.1822*** (0.043)	0.1101*** (0.035)	0.1822*** (0.042)	0.1098*** (0.036)
Constant	5.5083*** (0.021)	4.3741*** (0.500)	5.4171*** (0.021)	4.2544*** (0.508)
City-level control variables	No	Yes	No	Yes
Firm-level control variables	Yes	Yes	Yes	Yes
Year FEs	Yes	Yes	Yes	Yes
Firm FEs	Yes	Yes	Yes	Yes
N	1,647,253	1,629,402	1,651,422	1,633,535
R ²	0.784	0.787	0.786	0.789

Note: ***, **, * denote 1%, 5%, and 10% significance levels, respectively; standard errors in parentheses are clustered at the city-year level.

Table 8
Heterogeneity test: Energy dependence.

Variables	(1)	(2)	(3)	(4)
	performance1	performance2	performance1	performance2
did*high	0.1029* (0.054)	0.0048 (0.048)	0.0865* (0.047)	-0.0124 (0.039)
did*low	0.1979*** (0.054)	0.1320*** (0.043)	0.2020*** (0.053)	0.1357*** (0.044)
Constant	5.5083*** (0.021)	4.3716*** (0.500)	5.4172*** (0.021)	4.2515*** (0.508)
City-level control variables	No	Yes	No	Yes
Firm-level control variables	Yes	Yes	Yes	Yes
Year FEs	Yes	Yes	Yes	Yes
Firm FEs	Yes	Yes	Yes	Yes
N	1,647,253	1,629,402	1,651,422	1,633,535
R ²	0.784	0.787	0.786	0.789

Note: ***, **, * denote 1%, 5%, and 10% significance levels, respectively; standard errors in parentheses are clustered at the city-year level.

a large amount of capital investment. Capital-intensive enterprises are more sensitive to investment in capital which will be reflected in output, and considering that technological innovation also depends on capital input, the production performance of technology-intensive enterprises may also be significantly enhanced with the help of capital. Labor-intensive enterprises are not directly related to the energy industry; thus, it is presumed that labor-intensive enterprises are less affected by the WEOT project. To investigate this conjecture, we categorize industries into labor-intensive (*labor*), capital-intensive (*cap*), and technology-intensive (*tech*) by measuring the proportion of fixed assets and the proportion of R&D expenditure based on the industry classification of the Securities and Futures Commission. The empirical results are presented in Table 9, revealing that the estimated coefficients of *did*cap* and *did*tech* are significantly positive at 1% and 5% levels, respectively, and *did*cap* coefficients are both higher than the *did*tech* coefficients, while the estimated coefficients of *did*labor* are not significant. This result verifies the previous conjecture that the WEOT strategy implementation effectively improves the production performance of capital- and technology-intensive enterprises, and the effect on the production performance of labor-intensive enterprises is insignificant.

Table 9
Heterogeneity test: industry factor intensity.

Variables	(1)	(2)	(3)	(4)
	performance1	performance2	performance1	performance2
did*labor	0.0945** (0.038)	0.0375 (0.031)	0.0978*** (0.036)	0.0404 (0.030)
did*cap	0.1534*** (0.052)	0.1089** (0.050)	0.1597*** (0.051)	0.1149** (0.050)
did*tech	0.1431*** (0.034)	0.0922*** (0.033)	0.1438*** (0.033)	0.0926*** (0.034)
Constant	5.5089*** (0.021)	4.3677*** (0.501)	5.4177*** (0.021)	4.2480*** (0.509)
City-level control variables	No	Yes	No	Yes
Firm-level control variables	Yes	Yes	Yes	Yes
Year FEs	Yes	Yes	Yes	Yes
Firm FEs	Yes	Yes	Yes	Yes
N	1,647,253	1,629,402	1,651,422	1,633,535
R ²	0.784	0.787	0.786	0.789

Note: ***, **, * denote 1%, 5%, and 10% significance levels, respectively; standard errors in parentheses are clustered at the city-year level.

4.4.4. The heterogeneity of supportive policies

Considering the inherent state of limited resources, governments tend to prioritize the allocation of resources in essential industries that contribute the most to economic and social development. When oil enters a region, the government may endeavor to meet the energy needs of the key industries first; therefore, compared with key industries, non-central key industries are assumed to be more constrained by the lack of energy supply and more sensitive to the energy supply from the WEOT project implementation and to exhibit higher project-driven production performance improvement than those in the key central industries. We next take the key industries noted in the Chinese central government's 11th and 12th Five-Year Plans as the basis, using the industries with the two-digit codes C13–C43 as the central government's key support industries (*support*), while the remaining industries are the non-central government key support industries (*unsupport*). The regression results in Table 10 support our assumption. The coefficients of *did*support* and *did*unsupport* are both significantly positive at the 1% level; however, the coefficients of *did*unsupport* are much higher than those of *did*support*, indicating that both industries benefit from the WEOT project, but the benefit is greater for enterprises in the non-central key industries.

5. Mechanism analysis

The above demonstrates that the WEOT project has an enhancing effect on firms' production performance and heterogeneous effects on different firms; however, we must acknowledge that the improvement in production performance of firms along the route is not due to the WEOT project, but to the fact that the firms use the oil delivered by the WEOT project to increase production power and raw materials, which improves production performance. To further test whether the WEOT project alleviates enterprises' oil supply shortage, this study empirically examines whether the oil consumption of enterprises along the route significantly increases after the WEOT project implementation using oil consumption data from the National Enterprise Tax Survey Database. The empirical results reported in Table 11 show that the WEOT project implementation increased the oil consumption of enterprises along the route at the 1% level, indicating that the WEOT project effectively alleviates the shortage of oil supply to enterprises and provides energy support to improve performance.

Based on this conclusion, this section further constructs an econometric model to explore the mechanism of the role of the WEOT project implementation in promoting enterprises' production performance. The specific model is constructed as follows:

$$M_{it} = \alpha + \theta did_{it} + \beta_x X_{it} + \mu_i + \sigma_t + \varepsilon_{it} \quad (5)$$

where M_{it} represents the mechanism variables, including productivity enhancement (*tfp*) and enterprise agglomeration (*agg*) effects. The productivity enhancement effect measures enterprises' total factor productivity, and the enterprise agglomeration effect is measured by the annual number of industrial and commercial registered enterprises in the region. θ represents the regression coefficients of the effects of the WEOT project implementation on the above mechanism variables, and the remaining variables and indicators are consistent with the baseline model.

5.1. Productivity enhancement effect

Previous research has suggested that energy supply is important for firm productivity improvement (Grainger and Zhang, 2019) and inadequate energy supply may lead to loss of firm productivity (Allcott et al., 2016; Elliott et al., 2021); therefore, the WEOT project implementation may alleviate firms' oil supply shortages, enhancing firm productivity and firm production performance. We reference Olley and Parks (1996) to measure firm productivity and introduce it into Eq.(5) for regression

Table 10
Heterogeneity test: supportive policies.

Variables	(1)	(2)	(3)	(4)
	performance1	performance2	performance1	performance2
did*support	0.1650*** (0.044)	0.1032*** (0.037)	0.1675*** (0.043)	0.1054*** (0.037)
did*unsupport	0.2413*** (0.050)	0.1253*** (0.047)	0.2306*** (0.051)	0.1139** (0.049)
Constant	5.5082*** (0.021)	4.3753*** (0.500)	5.4171*** (0.021)	4.2547*** (0.508)
City-level control variables	No	Yes	No	Yes
Firm-level control variables	Yes	Yes	Yes	Yes
Year FEs	Yes	Yes	Yes	Yes
Firm FEs	Yes	Yes	Yes	Yes
N	1,647,253	1,629,402	1,651,422	1,633,535
R ²	0.784	0.787	0.786	0.789

Note: ***, **, * denote 1%, 5%, and 10% significance levels, respectively; standard errors in parentheses are clustered at the city-year level. C13-C43 refers to Processing of Food from Agricultural Products(C13), Manufacture of Foods(C14), Manufacture of Beverages(C15), Manufacture of Tobacco(C16), Manufacture of Textile (C17), Manufacture of Textile Wearing Apparel, Footware and Caps(C18), Manufacture of Leather, Fur, Feather and Related Products(C19), Processing of Timber, Manufacture of Wood, Bamboo, Rattan, Palm and Straw Products(C20), Manufacture of Furniture(C21), Manufacture of Paper and Paper Products(C22), Printing, Reproduction of Recording Media(C23), Manufacture of Articles For Culture, Education and Sport Activities(C24), Processing of Petroleum, Coking, Processing of Nuclear Fuel(C25), Manufacture of Raw Chemical Materials and Chemical Products(C26), Manufacture of Medicines(C27), Manufacture of Chemical Fibers(C28), Manufacture of Rubber(C29), Manufacture of Plastics(C30), Manufacture of Non-metallic Mineral Products(C31), Smelting and Pressing of Ferrous Metals(C32), Smelting and Pressing of Non-ferrous Metals(C33), Manufacture of Metal Products(C34), Manufacture of General Purpose Machinery(C35), Manufacture of Special Purpose Machinery(C36), Manufacture of Transport Equipment(C37), Electrical Machinery And Equipment Manufacturing(C38), Manufacture of Electrical Machinery and Equipment(C39), Manufacture of Communication Equipment, Computers and Other Electronic Equipment(C40), Manufacture of Measuring Instruments and Machinery for Cultural Activity and Office Work(C41), Manufacture of Artwork and Other Manufacturing(C42), Recycling and Disposal of Waste(C43).

Table 11
Oil consumption regression.

Variables	(1)	(2)
	petroleum	petroleum
did	0.0692*** (0.014)	0.0746*** (0.014)
Constant	-1.1461*** (0.060)	2.1995 (4.851)
City-level control variables	No	Yes
Firm-level control variables	Yes	Yes
Year FEs	Yes	Yes
Firm FEs	Yes	Yes
N	425,526	412,550
R ²	0.235	0.236

Note: ***, **, * denote 1%, 5%, and 10% significance levels, respectively; standard errors in parentheses are clustered at the city-year level.

analysis, and the regression results are presented in Table 12. Columns (1)–(2) report the regression results with firm-level control variables only and with both firm- and city-level control variables, respectively. The results show that WEOT project implementation significantly improves firms’ productivity, and effectively enhances production performance, regardless of whether control variables are included, validating

Table 12
Mechanism analysis: Productivity enhancement effect.

Variables	(1)	(2)
	tfp	tfp
did	0.1749*** (0.037)	0.0877** (0.034)
Constant	9.4331*** (0.023)	8.6053*** (0.689)
City-level control variables	No	Yes
Firm-level control variables	Yes	Yes
Year FEs	Yes	Yes
Firm FEs	Yes	Yes
N	1,647,007	1,629,318
R ²	0.890	0.893

Note: ***, **, * denote 1%, 5%, and 10% significance levels, respectively; standard errors in parentheses are clustered at the city-year level.

Hypothesis 2.

5.2. The agglomeration effect of enterprise

The industrial clustering effect can improve enterprises’ production performance through the division of labor and cooperation, technology and knowledge spillover. As a large-scale energy transportation strategy to solve the national energy supply and demand tension across regions, the WEOT project introduces a significant initial exogenous shock for the agglomeration of target industries and related industries, establishes a positive external environment for enterprise entry and agglomeration, and effectively promotes enterprise agglomeration in pilot regions. At the same time, since WEOT project implementation requires considerable infrastructure investment, it may have the most significant effect on the agglomeration of capital-intensive enterprises. We use city-level enterprise business registration data from 2006 to 2014, and construct enterprise agglomeration indicators (agg) based on these data to empirically test the effects. The results are presented in Table 13. Column (1) reports the effect of WEOT project implementation on firm agglomeration with the inclusion of control variables, while columns (2)–(3) report the effects on the agglomeration of capital-intensive and

Table 13
Mechanism analysis: The agglomeration effect of enterprise.

Variables	(1)	(2)	(3)
	Overall business sample	Non-Capital Intensive	Capital-intensive
	agg	agg	agg
did	0.1379*** (0.049)	-0.1076 (0.085)	0.1353*** (0.050)
Constant	3.2686*** (0.750)	1.3601 (1.014)	3.0512*** (0.774)
Control variables	Yes	Yes	Yes
Year FEs	Yes	Yes	Yes
Firm FEs	Yes	Yes	Yes
N	3948	3962	3948
R ²	0.959	0.913	0.959

Note: ***, **, * denote 1%, 5%, and 10% significance levels, respectively; standard errors in parentheses are clustered at the city-year level.

non-capital-intensive firms. The results show that WEOT project implementation effectively promotes regional enterprise capital-intensive enterprise agglomeration, but does not have agglomeration effects on non-capital-intensive enterprises. This finding is consistent with the nature of the high capital investment of the WEOT project. It also suggests that the WEOT project can enhance firm production performance through the firm agglomeration effect.

6. Further analysis

Previous sections demonstrate that the WEOT project has significantly increased the oil consumption of enterprises along the pipeline, and contributed to improving production performance through productivity enhancement and enterprise agglomeration effects; however, the stations along the WEOT pipelines are not completely homogeneous. For example, some pipelines can only receive oil from one oil injection point, and some can receive oil from two oil injection points, and some stations are oil export stations, while others are oil import stations. Therefore, we will compare the production performance of companies around different sites based on the above factors in Sections 6.1 and 6.2, respectively. We also measure whether the effect of the WEOT project on enterprises' production performance can spill over to a wider range of enterprises in Section 6.3.

6.1. Supply sources

There are two oil injection points along the Lan-Zheng-Chang pipeline, Lanzhou initial station and the Xianyang input pump station. Oil injection points only receive and output oil and do not input or use oil. Since the Lan-Zheng-Chang pipeline is a one-way transportation pipeline, Dingxi, Zhangjiachuan, and Baoji can only receive oil supply from one oil injection point (Lanzhou initial station), and Weinan, Sanmenxia, Luoyang, Zhengzhou, Xuchang, Zhumadian, Xinyang, Xiaogan, Wuhan, Xianning, Yueyang, and Changsha can receive oil supply from two oil injection points (Lanzhou initial station and Xianyang input pump station). More oil injection points serving a site indicate that it can receive a larger amount of oil. To examine the heterogeneity effect of the number of oil injection points on enterprises' production performance improvement, this section constructs the following interaction effect model.

$$performance_{i,t} = \alpha + \alpha_1 onedid_{it} + \alpha_2 twodid_{it} + \beta X_{i,t} + \gamma_t + \mu_i + \varepsilon_{i,t} \quad (6)$$

where $onedid_{it}$ and $twodid_{it}$ are dummy variables. If enterprise i receives oil supply from one oil injection point in a certain year and thereafter, then $onedid_{it}$ equals 1, otherwise it equals 0. Similarly, if enterprise i receives oil supply from two oil injection points in a certain year and thereafter, then $twodid_{it}$ is assigned to 1. The estimated coefficient α_1 indicates the impact of WEOT project implementation on the production performance of enterprises that only receive oil from a single oil injection point, and the estimated coefficient α_2 indicates the impact on the production performance of companies that can receive oil from two oil injection points. The regression results in Table 14 show that the estimated coefficients of $twodid_{it}$ are significantly larger than those of $onedid_{it}$, indicating that enterprises receiving oil supply from two oil injection points have a greater increase in economic performance than those receiving oil supply from only one oil injection point, which is most likely because of the greater supply from two oil injection points and the greater flexibility in securing oil supply.

6.2. Transportation direction

Two parties are involved in the WEOT project: the oil output-end and the oil input-end. The oil output-end takes advantage of its natural resources to drive employment and investment in the process of oil development and construction of related plants, bases, and stations,

Table 14 Differences in energy supply.

Variables	(1)	(2)
	performance1	performance2
Onedid	0.0348 (0.075)	0.0079 (0.071)
Twodid	0.1232*** (0.041)	0.1283*** (0.042)
Constant	4.3735*** (0.500)	4.2535*** (0.508)
Control variables	Yes	Yes
Year FEs	Yes	Yes
Firm FEs	Yes	Yes
N	1,629,402	1,633,535
R ²	0.787	0.790

Note: ***, **, * denote 1%, 5%, and 10% significance levels, respectively; standard errors in parentheses are clustered at the city-year level.

which promotes local economic growth. For the oil input-end, the oil supply meets local enterprises' demand for oil, relieves the oil supply tension, reduces energy costs, and promotes the production performance of the enterprises along the route. Since importing and exporting regions have different roles in WEOT project implementation, the effects of project shocks on the two may also differ. To explore this issue, this section constructs the following empirical model to reveal the differences in the effects of WEOT project implementation on the production performance improvement of enterprises in oil importing and oil exporting regions.

$$performance_{i,t} = \alpha + \alpha_1 didinput_{it} + \alpha_2 didoutput_{it} + \beta X_{i,t} + \gamma_t + \mu_i + \varepsilon_{i,t} \quad (7)$$

If enterprise i is located in oil input-end, then the year of project implementation and after $didinput_{it}$ equals 1. Similarly, when enterprise i is located in an oil exporting site, then the project implementation year and after $didoutput_{it}$ equals 1. The Eq.(7) focuses on the estimated coefficients α_1 and α_2 , which represent the impact of WEOT project implementation on the production performance of the oil importing enterprises and the oil exporting enterprises, respectively. The regression results are presented in Table 15, indicating that with or without the inclusion of control variables, WEOT project implementation significantly improves the production performance of oil importing enterprises, but does not significantly impact that of oil exporting enterprises. Obviously, oil importing regions tend to be energy poor compared with oil exporting regions; therefore, the WEOT project is more effective in improving the production performance of enterprises in importing regions as presumed by applying economic logic.

6.3. The spillover effect

The tests above confirm that WEOT project implementation has

Table 15 Oil input and output stations.

Variables	(1)	(2)
	performance1	performance2
didinput	0.1149*** (0.037)	0.1170*** (0.038)
didoutput	-0.0012 (0.066)	-0.0353 (0.032)
Constant	4.3745*** (0.500)	4.2550*** (0.508)
Control variables	Yes	Yes
Year FEs	Yes	Yes
Firm FEs	Yes	Yes
N	1,629,402	1,633,535
R ²	0.787	0.789

Note: ***, **, * denote 1%, 5%, and 10% significance levels, respectively; standard errors in parentheses are clustered at the city-year level.

significantly improved enterprises' production performance in prefecture-level cities along the pipeline route. However, as a national strategy pilot, the policy mission of the WEOT strategy is not only to alleviate the lack of energy supply in the key regions, but also to radiate and alleviate energy supply constraints in the regions surrounding the pilot areas. Accordingly, this section explores the spillover effect of the WEOT strategy. The introduction in Section 2 explained that the WEOT pipeline passes through the five provinces of Gansu, Shanxi, Henan, Hubei, and Hunan, with a total of 16 prefecture-level cities along the route (as shown in Table 1). In the baseline regression, the treated group is the 16 prefecture-level cities along the route, and the control group is cities in other provinces except for the five provinces. This section expands the treated group based on the sample of the baseline regression and conducts two more regressions. The first regression examines cities that are adjacent to the 16 cities along the route as the treated group (excluding the 16 cities along the route), and the control group is the same as the baseline regression. The regression results are shown in columns (1)–(2) of Table 16. The coefficients of the interaction terms of the dummy variables are significant at the 1% level when either enterprises' gross industrial output value or product sales revenue is used as the explanatory variable. This finding indicates that WEOT project implementation not only effectively improves the production performance of enterprises in cities along the pipeline, but also has spillover effects that improve the production performance of enterprises in the cities adjacent to the 16 cities along the pipeline. The second regression examines cities in the five provinces excluding the 16 cities along the pipeline as the treated group, and the control group is the same as the baseline regression, and the regression results are shown in columns (3)–(4) of Table 16. The estimated coefficients of the core explanatory variables are significantly positive at the 5% level, indicating that the WEOT strategy not only significantly improves the production performance of enterprises along the route, but also improves the production performance of enterprises in the cities adjacent to the 16 cities along the route and even other cities in the same province.

7. Conclusions and recommendations

Energy supply is a crucial matter of production stability and national security. As a major energy-producing and consuming country, China has always considered securing energy supply as a top priority of energy work. At present, China's fossil energy accounts for 83.4% of the total energy use, oil and gas remain the main force of energy supply; however, most of the country's oil reserves are concentrated in the western region, while consumption is concentrated in the eastern region, resulting in a mismatch between China's oil distribution and energy demand. The major national WEOT project was implemented to make full use of domestic resources and advance oil resource allocation efficiency and

energy self-sufficiency. The project currently supplies oil to central China but has not yet reached eastern China. This study first uses panel data from industrial enterprises in China from 2006 to 2014 to empirically assess the impact of WEOT project implementation on industrial enterprises' production performance and the underlying mechanisms. We then explore the impact of the project based on different ownership, factor-intensive industries, industries with different government support, and cities with different resource endowments. Finally, we further explore the impact of different oil supplies and stations with different functions and analyze the possible spillover effects of the WEOT project.

The findings reveal that (1) the WEOT project significantly improves the production performance of enterprises along the route, and this effect is primarily achieved by increasing enterprise productivity and promoting enterprise agglomeration. (2) In terms of enterprise types, compared with labor-intensive enterprises, SOEs, and enterprises in key central support industries, non-labor-intensive enterprises, non-SOEs, and enterprises in non-key central support industries are more sensitive to WEOT project implementation. Regarding urban resource status, the WEOT project has a greater driving effect on low-energy-dependent cities, high-energy supply areas, and energy input regions. (3) The WEOT project has a spillover effect on neighboring cities' production performance and even enterprises in the province. Referencing these findings, we propose three recommendations.

First, the layout of the WEOT project should be extended to east and south China. The WEOT project reduces oil costs and improves the economic performance of enterprises in oil importing areas; however, until 2022, more than 20 years after the official implementation of China's WEOT project, many regions in China still experience oil tension. Therefore, policymakers should continue to expand the WEOT project strategically, further rationalize the planning, and improve the construction of China's oil transportation network, enhance the level of regional mutual assistance and multi-energy complementarity, strengthen the construction of feeder lines, reduce transportation costs, optimize the distribution pattern, and promote the WEOT project to benefit more provinces and regions. In addition, based on the high cost of pipeline operation and maintenance, regional governments should coordinate and increase financial investment to provide pipeline maintenance subsidies to certain difficult areas to avoid the contradictory phenomenon of having pipes but not using them.

Second, expanding the spatial spillover effect of WEOT project implementation will further alleviate the energy supply and demand tensions in the pilot periphery. From the perspective of strategic construction, it is essential to increase the number of WEOT project oil pipelines and expand the pipeline network for refined oil products to increase project coverage and ease energy supply tensions. Increasing the number of pipelines will further expand the coverage of the pilot project surrounding areas to enhance the spatial spillover effect and relieve oil supply tensions in neighboring areas. At the governmental level, neighboring governments should actively establish regional energy synergy and mutual assistance mechanisms, strengthen energy industry cooperation, and promote the formation of a whole industry chain system based on energy sharing. For example, the neighboring areas of the pilot area can transfer energy-intensive upstream industries to the pilot project area to address the problem of tight oil supply, while the pilot area can transfer non-energy-intensive downstream industries to the pilot area to fully leverage the resource advantages of each region and strengthen the spatial spillover of policy effects.

Third, prioritize the fairness of energy transportation policies and promote the coordinated development of regional economies. The results of the heterogeneity analysis demonstrate that WEOT strategy implementation has a more pronounced effect on the production performance of the importing regions, non-central key support industries, capital-intensive and technology-intensive industries, and non-state enterprises. This result fully illustrates the importance and sensitivity of oil supply to such enterprises' production. Therefore, it is essential to abandon the previous tendency toward policies favoring SOEs and

Table 16
Spillover effects.

Variables	(1)	(2)	(3)	(4)
	Adjacent cities as treated groups		Other cities in 5 provinces as treated groups	
	performance1	performance2	performance1	performance2
did	0.0910*** (0.028)	0.0889*** (0.029)	0.0390** (0.018)	0.0582*** (0.017)
Constant	4.3769*** (0.496)	4.2542*** (0.505)	4.2643*** (0.501)	4.1637*** (0.508)
Control variables	Yes	Yes	Yes	Yes
Year FEs	Yes	Yes	Yes	Yes
Firm FEs	Yes	Yes	Yes	Yes
N	1,634,854	1,639,008	1,712,173	1,716,437
R ²	0.788	0.790	0.789	0.791

Note: ***, **, * denote 1%, 5%, and 10% significance levels, respectively; standard errors in parentheses are clustered at the city-year level.

centrally supported enterprises, and shift policies that focus more on non-SOEs, non-centrally supported enterprises, and emerging capital-intensive and technology-intensive industries. This approach will subsequently improve the allocation effect of oil resources and leverage the enhancement effect of WEOT project implementation on enterprise production. Notably, although the WEOT project implementation primarily improves the production performance of enterprises in input cities, the energy transportation strategy should be implemented to ensure adequate energy supply in output cities to avoid the problem of energy supply tension in output locations due to overweight delivery targets, as evidenced by the large-scale and persistent electricity shortage in Sichuan in 2022.

CRedit authorship contribution statement

Weifen Lin: Data curation, Formal analysis, Methodology, Project administration, Writing – original draft, Writing – review & editing. **Xinyue Tong:** Data curation, Investigation, Methodology, Resources, Writing – original draft, Writing – review & editing. **Yao Hu:** Formal analysis, Methodology, Software, Writing – review & editing. **Hui Wang:** Conceptualization, Investigation, Resources, Supervision, Writing – review & editing.

Declaration of Competing Interest

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

Appendix A. Supplementary data

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