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The impact of China's 'Atmosphere Ten Articles' policy on total factor productivity of energy exploitation: Empirical evidence using synthetic control methods

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ABSTRACT

Implementation of the atmospheric policy is important to influence energy production and exploitation. By implementing the atmospheric policy, this study has simulated and compared the energy exploitation total factor productivity (TFP) change path for the energy extraction and enrichment areas applying the synthetic control method, using Chinese panel data for the period from 2007 to 2016. The results show that the atmospheric policy will help the growth of TFP in Shandong, Anhui, and Shanxi, but the impact in most areas is not observable, and the lagging effect of atmospheric policy is conspicuous in Gansu, Shaanxi, Liaoning, and other places. Based on this, the study proposes three mechanisms to explain how atmospheric policy affects energy production TFP and uses a panel Tobit model to test the path of action. The test results show that implementation of the atmospheric policy has not improved energy exploitation TFP effectively, but it has to be implemented. Time effect and the model estimation results show that the atmospheric policy and technological innovations are more conducive to improving energy exploitation TFP, but the role of industrial division of labour and the energy market price mechanism makes it difficult to promote energy exploitation TFP. The influence of atmospheric policy varies in different regions and is inconsistent in the northeast and east. The regional atmospheric policy can significantly promote energy exploitation TFP in the region, but the central and western regions do not show significant inverse relationship with the energy exploitation TFP.

1. Introduction

Carbon dioxide (CO_2) emissions from burning fossil fuels account for three-fourth of annual anthropogenic greenhouse gas (GHG) emissions (Erickson et al., 2018). According to the Paris Climate Agreement, CO_2 emissions from fossil fuels must reduce to net zero by the end of the present century (Rogelj et al., 2018). The existing literature suggests that energy and climate policies can effectively reduce CO_2 emissions from fossil energy sources (Rogelj et al., 2018). In fact, for nearly three decades, governments and researchers had focused on mitigating the consumption of fossil fuels, fossil fuel combustion and emissions through measures such as carbon taxes and emissions trading systems, energy efficiency standards, and incentives to reward zero emissions. These policy measures have effectively slowed down the release of greenhouse gas emissions, but there is still a large gap between energy production and consumption between countries. As of 2017, coal, oil, and natural gas-based fossil fuels accounted for 82.9% of global energy consumption, that is, 82% of energy consumption for the US, 92% for India, and 93% for China, respectively, based on the data from the National Energy Information Economics Data Center (https://www.energy.gov/energy-economy). From the perspective of supply-side climate policy, some researchers believed that exploitation of fossil fuels can restrict fossil fuel supply and consumption, thereby reducing greenhouse gas emissions from fossil fuel combustion. Although it is not uncommon to analyse how implementation of the atmospheric policy in specific regions affects gas emissions from the supply side, the existing body of literature lacks analysis of how specific jurisdictions affect energy, especially exploitation of fossil energy sources.

Production of fossil fuels is part of the overall climate strategy and it is critical to national energy security, but fossil energy exploitation could also lead to depletion. The problems of air pollution accompanying China's rapid economic growth have attracted more attention.

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Therefore, the government's determination to prevent air pollution is unprecedentedly firm. In September 2013, the State Council promulgated an action plan titled '*the Action Plan on Prevention and Control of Air Pollution*' (hereinafter, referred to as 'Atmosphere Ten Articles' policy), and introduced ten measures for preventing air pollution and control. The ten measures consist of increasing the supply of natural gas, coal-based natural gas, and coal-bed methane, and accelerating the use of alternative clean energy. The Beijing-Tianjin-Hebei, Yangtze River Economic Delta, and the Pearl River Delta regions should accelerate the closure of coal-fired facilities of existing industries, and replace with natural gas and promote the use of clean coal. To implement the State Council's 'Atmosphere Ten Articles' policy, local governments successively announced regional action plans for preventing air pollution. However, it is not clear how atmospheric policies promoted by the central government and regional governments will affect energy exploitation. Furthermore, the response to top-level design policy in different regions remains to be clarified. This study examines if the enactment and implementation of the 'Atmosphere Ten Articles' policy has improved the energy-generating total factor productivity (TFP) in fossil energy exploitation and enrichment areas and also examines if there is consistency in the impact on different regions. These inferences would help to propose energy conservation and optimization of energy exploitation structures for different regional atmospheric policy responses.

The structure of this paper is organized as follows. Section 1 is this introduction; Section 2 reviews the relevant literature. Section 3 introduces the research methodology and describes data and variables. Section 4 presents the results of the atmospheric policy influenced TFP by Synthetic control method (SCM). Section 5 examines the mechanism between atmospheric policy and TFP using panel Tobit model. Section 6 concludes with policy proposals.

2. Literature review

From the perspective of energy life cycle assessment (Ou et al., 2010; Mikhail et al., 2006; Hekkert et al., 2005), energy is subject to exploitation, that is, consumption, emissions, and the process also involves economic theory. Ou et al. (2010) used the energy life cycle studied the policy and the fossil energy use, Mikhail et al. (2006) discussed relation between the fuel use and the gasoline vehicles by life cycle assessment. The production quota for fossil fuels is rooted in economic theory, which reduces fossil fuel production by limiting greenhouse gas emissions. Research on energy economy focuses on the demand side of energy management, including energy efficiency (Orgerie et al., 2014; Ayres et al., 2007), energy demand forecast , strategic energy reserves (Thien et al., 2017), the relationship between energy consumption and economic growth (Nguyen, 1984; Lee and Chang, 2008; Wolde-Rufael, 2013), technological progress and energy intensity (Mulder and Groot, 2012, 2014; Voigt et al., 2014; Cao, 2017; Wurlod and Noailly, 2018). For example, Mulder and Groot (2012, 2014), Voigt et al. (2014) analysed structural changes in energy intensity between countries from technological progress perspective, However, research on energy production is not vast, and systematic research on energy exploitation is not comprehensive (Wang et al., 2013). In terms of energy exploitation, the earliest literature traces back to Hotelling (1931), who postulated the 'Hotelling Rule' through social values to derive the optimal extraction path for natural resources, including energy. On this basis, some scholars re-examined the applicability of the 'Hotelling Rule', including rebuilding resource exploitation and economic growth under conditions such as fixed or declining marginal exploitation costs, changes in demand elasticity or discount rate, market monopoly structure, and models of technological progress (Pindyck, 1980; Harker, 1984; Eswaran and Lewis, 1985; Stern, 1993; Wang et al., 2017). For example, Wang et al. (2017), Wang and Zhang (2018) examined key conceptual dimensions for relative technological innovation of China's coal mine. Unlike the early research methods of Pindyck (1980), Patrick (1984), etc., Wang et al. (2017), Wang and Zhang (2018) used data envelopment analysis (DEA) models to study technological advances in energy markets and their effects.

In the context of consumption of energy sourced from fossil fuels, scholars focused on aspects such as environmental and climate changes caused by the consumption of such energy sources, especially environmental pollution due to fossil fuel combustion. Combined with policy instrumental variables, some scholars study the effects of exogenous shocks and policies on air pollution, such as Chen et al. (2013), He et al. (2016), and Cao et al. (2011). These scholars studied the impact of limiting measures on air quality, based on the objective of hosting the Olympic Games in Beijing. Chen et al. (2013) and He et al. (2016) believed that the incident, the Olympic Games at Beijing, brought limited discharge measures that effectively controlled air pollution and improved air quality, but Cao et al. (2011) concluded that the effect of this limit on air quality was not significant. Xi and Liang (2015) also linked air pollution problems with economic phenomena such as oil price changes and rail transit. Luo and Li (2018) studied the impact of the 'Atmosphere Ten Articles' policy promoted by the Chinese government. However, policy research on the front-end energy market needs to expand. Moreover, the energy exploitation industry has its own peculiarity compared to other industrial sectors. The traditional TFP measurement framework is difficult to reflect the real productivity changes completely, that is, in addition to input and output, technological progress and scale returns, depletion of energy resources, environmental pollution caused by exploitation of energy resources may affect the TFP measure. Therefore, based on the traditional TFP measurement model, it is necessary to incorporate these factors to establish a more comprehensive and reasonable measurement system for the energy factor.

This study mainly contributes the SCM model, which focuses on the 'Atmosphere Ten Articles' policy. Specifically, whether the policy helps to enhance energy extraction and TFP, optimize energy extraction if the effect is obvious, and understand the role of 'Atmosphere Ten Articles' policy in energy exploration TFP; base panel Tobit energy policy exploitation empirical atmospheric model TFP specific mechanism of action. Since SCM extends the DID method, the non-parametric estimation method improves accuracy of the policy evaluation effect. At the same time, appropriate weights are selected through observable data to avoid weight errors caused by subjectivity, thereby reducing any bias in the policy evaluation results. To this end, this study collected data generated by energy exploitation and energy use processes for 30 provincial regions in China for the period from 2007 to 2016 and implementation data for the 'Atmosphere Ten Articles' policy, combined with SCM for analysis.

In summary, this study's contribution includes: (1)Assess the impact of the 'Atmosphere Ten Articles' policy on the TFP by SCM model; (2) Construct the mechanism of 'Atmosphere Ten Articles' policy on the TFP; (3)Use a panel TOBIT random effect model to analyse the 'Atmosphere Ten Articles' policy affecting TFP; (4)Estimate results are measured by statistical feature analysis of robust features.

3. Methods

3.1. Synthetic control method

SCM is a 'counter-fact' analysis technique proposed by Abadie and Gardeazabal (2003) to study the economic costs of terrorist activities in the Basque country of Spain. The main research concepts of SCM set out in this study are as follows: First, we use the observed fact data and the decision-making unit to construct the 'counter-fact' unit. Second, comparison of the data values before and after the implementation of the atmospheric policy to evaluate the impact. The principle specific to SCM is as follows: assuming that energy exploitation TFP can be observed, C+1 represents the object (province or city); the first is an energy-rich exploitation province in the time zone affected by the 'Atmosphere Ten Articles' policy as the target area to be processed. The other provinces are defined as the control objects, and the above-mentioned provinces can observe the TFP growth in energy extraction during T period. It indicates that the TFP_{it}^N condition of energy extraction has not been implemented in the 'Atmosphere Ten Articles' policy of the energy extraction enrichment area; TFP_{it} indicates that the energy exploitation enrichment area is subject to the energy exploitation TFP implemented by the atmospheric policy. The mode is given as:

$$TFP_{it} = TFP_{it}^N + D_{it}\alpha_{it}, \tag{1}$$

where D_{it} is the dummy variable, when the i province t time by the atmospheric policy implementation effect, $D_{it} = 1$, the opposite is 0. For provinces that are not subject to the impact of implementation of the atmospheric policy, the energy-rich regions have $TFP_{it} = TFP_{it}^N$. Primarily, this is based on the following considerations: implementation of the atmospheric policy after t period affected the i energy-producing province and the target converted into an estimate α_{it}. When $D_{it} = 1$, $t > T_0$, there $\alpha_{it} = TFP_{it} - TFP_{it}^N$. Therefore, this study is estimated for α_{it}. The aim of processing is that the target region can be observed, that is, TFP_{it} can be observed, but TFP_{it}^N is not observed. Therefore, it is necessary to combine the Abdiel factor model to estimate the 'counter-factual' of the target area:

$$TFP_{it}^N = \delta_t + \theta_t Z_i + \lambda_t \mu_i + \varepsilon_{it} \tag{2}$$

δ_t is a time trend; Z_i is a control variable that is not affected by the implementation of the 'Atmosphere Ten Articles' policy; θ_t is a $1 \times r$ dimensional unknown vector of parameters, which λ_t is a common factor vector that cannot be observed in the $1 \times F$ dimension, and μ_i is a 1×1 dimensional unobservable fixed effect; ε_{it} is an unobservable short-term shock, $E(\varepsilon_{it}) = 0$. Assume that the first energy-rich provinces affected by the implementation of the atmospheric policy, the energy exploration TFP for other C_i provinces has not been affected, $i = 2, \cdots, C + 1$. Therefore, to obtain the influence of the atmospheric policy on energy exploitation in the enrichment area, it is necessary to assume that there is no TFP for energy exploitation when the atmospheric policy is implemented. The usual solution is to simulate the characteristics of the treatment group by weighting the control group provinces: assuming a $K \times 1$ dimensional vector weights $W = (w_2, w_3, \cdots, w_{k+1})$, satisfied $w_k \geq 0$ and $w_2 + w_3 + w_{k+1} = 1$. The specific value of each vector W is a specific weight for the K provinces.

$$\sum_{k=2}^{K+1} w_k TFP_{kt} = \partial_t + \theta_t \sum_{k=2}^{K+1} w_k Z_k + \lambda_t \sum_{k=2}^{K+1} w_k \mu_k + \sum_{k=2}^{K+1} w_k \varepsilon_{kt} \tag{3}$$

Suppose there is a vector group $W^* = (w_2^*, w_3^*, \cdots, w_{k+1}^*)'$, there is

$$\sum_{k=2}^{K+1} w_k^* TFP_{k1} = TFP_{11}, \sum_{k=2}^{K+1} w_k^* TFP_{kT_0} = TFP_{1T_0}, \sum_{k=2}^{K+1} w_k^* Z_k = Z_1 \tag{4}$$

If $\sum_{i=1}^{T_0} \lambda_t^{'} \lambda_t$ is not singular, then there are:

$$TFP_{it}^N - \sum_{k=2}^{K+1} w_k^* TFP_{kt} = \sum_{k=2}^{K+1} w_k^* \sum_{s=1}^{T_0} \lambda_t \left(\sum_{i=1}^{T_0} \lambda_t^1 \lambda_t \right)^{-1} \lambda_s^1 (\varepsilon_{kt} - \varepsilon_{is}) - \sum_{k=2}^{K+1} w_k^* (\varepsilon_{kt} - \varepsilon_{is}) \tag{5}$$

Abadie et al. (2010) demonstrated that the right side of the mean general formula converges to 0, that is $TFP_{it}^N - \sum_{k=2}^{K+1} w_k^* TFP_{kt} \rightarrow 0$, then we use $\sum_{k=2}^{K+1} w_k^* TFP_{kt}$ as an unbiased estimate of TFP_{it}^N to approximate TFP_{it}^N, and it is possible to obtain an estimate α_{it}:

$$\widehat{\alpha_{it}} = TFP_{it}^N - \sum_{k=2}^{K+1} w_k^* TFP_{kt} \tag{6}$$

3.2. Analysis mechanism for policy implementation on TFP

The SCM method can assess the economic impact of policies accurately but lacks specific analysis of the mechanism. This study proposes the mechanism of atmospheric policy affecting energy exploitation TFP, as shown in Fig. 1. This study argues that atmospheric policy affects energy exploitation TFP mainly through technological innovation and cost internalization to solve or reduce the cost of energy exploitation process, optimizes energy exploitation and improves energy exploitation TFP growth. Primarily, technological innovation and cost internalization play through three mechanisms:

3.2.1. The demonstrative effect of the regional economic linkage

The so-called regional economic linkage demonstration effect means that the proximity of inter-regional economic linkages will lead to imitation by a few surrounding provinces, while the initial provinces play a demonstration role (Braakmann and Vogel, 2011; Elsner, 2013; Ivlevs, 2013). Implementation of the atmospheric policy will likely affect energy exploitation and help to achieve effectiveness and promote imitation in the surrounding provinces. Specifically, the demonstration effect of regional economic linkages in energy extraction and enrichment areas reduces energy extraction costs and technological innovation through the following aspects:

(1) Complementarity of economic resources. The academic community has always recognized complementarity of resources between regions, and this is particularly evident in the cooperation and complementarity of energy exploitation. For example, labour and capital required for energy exploitation can flow to the unproductive areas by enriching provinces, while energy exploitation in poor areas can meet the consumption needs of the rich provinces.
(2) Implementation of air pollution control regulations. The country promoted the 'Atmosphere Ten Articles' policy. All the provinces and municipalities introduced prevention and control regulations for air pollution at different periods. This demonstration strengthens the influence of atmospheric policies on the one hand and plays a demonstration role for other provinces. At the same time, introducing technology in the energy exploitation process and improving the level of technological innovation can save on labour and improve productivity, and this contributes to the demonstrated driving effect.

3.2.2. Industrial division of labour

The so-called industrial division of labour refers to the division of labour and layout of inter-regional development, sales, and consumption, thereby optimizing the type of exploitation and resource allocation for energy extraction. Specifically, the degree of coordination in industrial division of labour reduces costs, and internalization of costs is achieved through the following ways:

(1) The profitable industries are arranged according to the factor endowment theory, and the front-end profitable industries are developed by relying on their own advantageous resources and location characteristics to reduce transportation costs in energy extraction (Krugman, 1991).
(2) The exploitation industry is developed according to the industry life cycle theory. The energy extraction process is optimized through the sequential transfer of front-end exploitation.

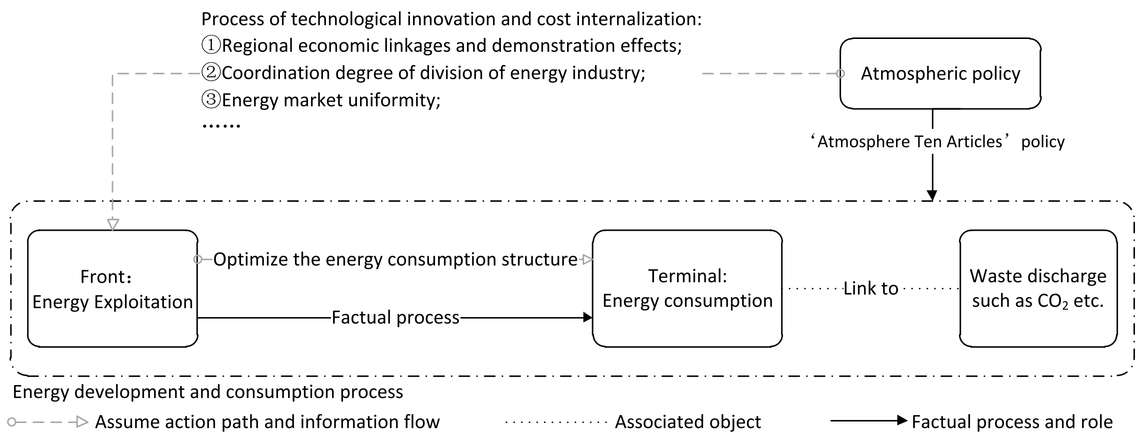

Fig. 1. Atmospheric mechanism affects the action of energy exploitation TFP growth.

3.2.3. *Degree of coordination in the energy market*

Coordination in the so-called energy market refers to the degree of unified market development in which energy exploitation or sales, consumers' industrial chain forms an orderly competition among provinces, and optimizes allocation of energy resources (Dahlman, 2004; Xheneti and Bartlett, 2012). Specifically, the degree of unified coordination is achieved in the energy market through the following:

(1) Formation of a large market. The traditional economies of scale indicate that economies of scale can be realized by expanding the scale of industries or enterprises, thereby realizing internalization of enterprise costs and improved efficiency. Through the complete industrial chain, the energy market can effectively reduce energy exploitation costs, internalize the energy market, and decrease the unified barriers to the energy market.
(2) Systematic competition can link energy development and reduce energy exploitation costs.

3.3. *Data background*

China has continuously published three lists of cities with depleted resource supply. Due to limited data samples of cities with depleted energy resources and inconsistent data statistics (see Appendix Table A1), this study classifies such province or city units and divides research objects into two groups: energy exploitation of enrichment areas and energy exploitation of poor areas. This is mainly because these cities provide sufficient resource reserves for energy exploitation and enter the later stage of resource development and utilization. Energy resources are abundant, but they need to be transformed. Thus, this study has 23 provincial administrative districts comprising cities with energy exploitation and depletion. Since resource depletion types in Guizhou and Yunnan provinces are mainly non-ferrous metals such as ores, they are eliminated from the treatment group, and 21 samples are finally formed for the study.

This study selects data for 30 provinces during 2007–2016 in China. Among the data, 21 provinces with energy enrichment areas are defined as the Treated Group, and the remaining 9 provinces are considered as the Control Group. To distinguish the influence of spatial heterogeneity, according to the regional economic classification published by the National Bureau of Statistics, this study divides the sample into eastern region (Guangdong, Hainan, Hebei, Jiangsu, and Shandong), central region (Anhui, Henan, Hubei, Hunan, Jiangxi and Shanxi), western region (Gansu, Guangxi, Inner Mongolia, Ningxia, Shaanxi, Sichuan, Chongqing), and the northeast (Heilongjiang, Jilin and Liaoning). The predictor data included are derived from the domestic statistical yearbooks in our study. Among them, the number of people engaged in energy exploitation, investment in energy exploitation and selection industry, land area occupied for exploitation, and major energy production in industrial fixed assets investment are derived from the *China Statistical Yearbook* and *China Energy Statistical Yearbook*. Labour productivity, capital productivity, comprehensive energy consumption rate, environmental quality index, environmental pollution index, and comprehensive utilization rate of solid industrial waste are obtained from the *China Science and Technology Statistical Yearbook*. Some missing data are supplemented from the statistical yearbooks of the corresponding provinces. The total amount of CO_2 emissions is calculated according to the results of the IPCC Guidelines for Carbon Emissions for the 30 provinces. Unless otherwise stated, this study does not calculate energy data for Tibet, Hong Kong, Macau, and Taiwan.

The main purpose of this study is to use the weighted average of the control group to simulate the 'counterfactual' energy exploitation TFP without implementing the atmospheric policy for the energy extraction enrichment area, and then comparing it with the energy exploitation TFP affected by the atmospheric policy in the real energy exploitation enrichment area. We estimate the impact of implementation of the atmospheric policy on energy exploitation TFP and estimate the impact of atmospheric policy on TFP effects in energy extraction. According to the SCM steps, when selecting weights, it is necessary to make the energy influencing factors of the synthetic energy extraction and enrichment areas as consistent as possible in the target area before the implementing the atmospheric policy.

3.3.1. *Control variables*

The predictive control variables selected in this study include industrial fixed asset investment (*CAP*), labour productivity (*LAI*), capital productivity (*KRI*), comprehensive energy production rate (*CEI*),[1] environmental quality index (*EQI*),[2] environmental pollution index (*EPI*), and comprehensive utilization of solid industrial waste (*ISI*). Among them, environmental quality index is based on the planning targets defined in the National 12th Five-Year Plan for discharge of sulphur dioxide emissions in the air (Ministry of Environmental Protection of the People's Republic of China, National Development and Reform Commission, Ministry of Finance of the People's Republic of China, 2012), discharge of chemical oxygen demand in water, and

[1] We referred to the "National Creation System Series Survey Report" published by the Ministry of Science and Technology of China, the series of reports for details at http://www.most.gov.cn/cxdc/cxdcpjbg/201710/P020171031359500007876.pdf. There listed the unify and standardize methods.

[2] We can see the detailinformation at http://www.most.gov.cn/cxdc/cxdcpjbg/201710/P020171031359500007876.pdf.

number of days above the second highest level of air pollution. The formula for calculating is given as:

$$EQI = SHL \times 0.6 + RCO \times 0.2 + SDE \times 0.2 \tag{7}$$

$$ISI = \frac{ISWU}{ISWP + USC} \times 100\% \tag{8}$$

where SHL is the number of days above the second highest level of air pollution or more, RCO is the compliance rate of chemical oxygen demand in wastewater, SDE is the sulphur dioxide emissions compliance rate, $ISWU$ is industrial solid waste utilization amount, $ISWP$ is industrial solid wastes produced, USC is utilization in previous years, storage capacity.

The greater the number of products per unit time the higher is labor productivity, it can help to improve technological progress to promote energy exploitation TFP. Technological progress can improve capital productivity and further enhance technological innovation and introduction of technology, improve management, and help prevent the decline in capital productivity. The greater the overall energy output rate, the higher is the efficiency of energy use. The environmental quality index is a measure of the quality of the natural environment.

The environmental governance index focuses on the treatment of major pollutants, hazardous wastes, domestic waste and sewage, and investment in pollution control, and the work carried out by local governments to prevent pollution for environmental management. Comprehensive utilization of industrial solid waste refers to solid waste generated during industrial production processes, but it involves energy extraction work.

3.3.2. Core variable

In terms of measurement of energy extraction TFP (shown in Table 1), the selected input variables mainly consider two dimensions: capital and labour, including number of employees in the energy extraction industry at the end of the year (LAB) and investment in fixed assets for the energy exploitation industry (KFA). Among them, fixed assets investment KFA of the main energy exploitation and selection industry includes the investment in fixed assets made by the state-owned economy in coal, oil, and natural gas exploitation industry, excluding the state-owned economic power, steam, hot water production, and investment in the fixed assets of the supply industry. Fixed asset investment in energy use and distribution, which is mainly used to measure the financial investment necessary for energy exploitation and development, is a direct and important factor for TFP; number of employees in the energy extraction industry at the end of the year is used to characterize the labour input in the development process. In terms of output for energy extraction, pursuing previous studies on important energy extraction variables (such as Wang et al., 2018), selection of desired output variable indicators with average annual production of primary energy, where the energy sources include coal, coke, crude oil, gasoline for the production of kerosene, diesel, fuel oil, and natural gas, which is converted into 10,000 tons. The undesired output indicators mainly include the mine area and carbon dioxide emissions encroached by energy exploitation and development.

Combining Wang and Feng (2017) on CO_2 Emissions in Energy Mining Industry (Zhao et al., 2016), The calculation of TFP for energy extraction involves the annual average production of main energy (desired output) and land encroachment and carbon dioxide emissions caused by energy exploitation (undesired output) in our works. Therefore, it is difficult to measure the energy exploitation TFP with the traditional TFP measurement method. Based on Peng et al.(2019), the global Malmquist - Luenberger index method (GML) is used to avoid the deficiencies in the geometric mean of production efficiency in the adjacent periods as it does not satisfy cyclic accumulation (Oh and Heshmati, 2010; Shao et al., 2016; Liu et al., 2017), which is a common method of data envelopment analysis (DEA). The calculation formula is as follow Eq. (9):

$$GML_t^{t+1} = \left[\frac{1 + \overline{D}_0^t(x^t, y^t, b^t; y^t, -b^t)}{1 + \overline{D}_0^t\left(x^{t+1}, y^{t+1}, b^{t+1}; y^{t+1}, -b^{t+1}\right)} \, \frac{1 + \overline{D}_0^{t+1}(x^t, y^t, b^t; y^t, -b^t)}{1 + \overline{D}_0^{t+1}\left(x^{t+1}, y^{t+1}, b^{t+1}; y^{t+1}, -b^{t+1}\right)} \right]^{0.5} \tag{9}$$

where x is the energy production inputs LAB and KFA, y is the production volume P produced by energy exploitation activities; b is the undesired output of land (EL) and CO_2 produced by energy exploitation activities (Eggleston et al., 2006), D is the directional distance function (DDF). Definition the DDF (using Eq. (10) and Eq. (11)):

$$\overline{D}_0^t(x^t, y^t, b^t; y^t, -b^t) = sup\{\beta : D_0(x, (y, b) + \beta(y, b)) \le 1\} \tag{10}$$

$$D_0(y, b) = inf\{\tau : ((y, b) / \tau) \in p(x)\}, p(x) = \{(y, b) : x \to (y, b)\} \tag{11}$$

where sup is defined as the smallest upper bound of a collection, inf is defined as the largest lower bound of an aggregate, β is the ineffective part that needs to be adjusted, and the measure is the maximum ratio of the decrease in the undesired output b and the increase in the expected output y along the vector (y, -b), at the fixed input and the technical level.

3.4. Descriptive statistics

Table 2 presents the descriptive statistics for the main variables. Further, the TFP (Treated Group) situation of energy extraction affected by atmospheric policies in each energy extraction and enrichment area studied is the same as that of the control group TFP (Control Group) T-test, which is also listed in Table 2. In this study, 21 energy-exploitation areas affected by atmospheric policies are used for the experimental analysis, and the remaining nine provincial-level administrative regions formed the control group.

The synthesis process is implemented by STATA software. The solid line in Fig. 2 shows the average trend of the nine control groups after averaging with the energy-exploitation areas affected by 'Atmosphere Ten Articles'. It can be seen that from 2007 to 2016, the average change in energy extraction TFP is not significant and the overall situation fluctuated, declining from 2007 to 2009, recovering slightly from 2009 to 2010, remaining unchanged from 2011 to 2013, rebounding between 2013 and 2014, declining slightly in 2015, and recovering by around 2012. Although there are many factors affecting the TFP of energy exploitation, as technological progress increases, the TFP does not increase, indicating that it is subject to the constraints of the macro environment. Moreover, most of the current technology use in energy exploitation is insufficient, and still adopts a low-cost, low-price competition model, which is one of the reasons why the TFP cannot be improved.

The dotted line in Fig. 2 shows the actual energy exploitation TFP situation between Beijing, Fujian, Qinghai, Shanghai, Tianjin, Xinjiang, Zhejiang, Guizhou, and Yunnan from 2007 to 2016. In 2013, the TFP of energy exploitation in Beijing, Fujian, Xinjiang, Guizhou, and Yunnan was above average during different years; while the TFP of energy exploitation in Qinghai and Zhejiang was below average in different

Table 1
Descriptive statistics for TFP measurement variables for energy exploitation.

Var	Name	Mean	S.D	Min	p50	Max	Unit
Input	Number of people engaged in energy extraction (*LAB*)	18.88	20.07	0.04	12.58	103	people
	Investment in fixed assets in energy exploitation and selection industry (*KFA*)	76.2	124.9	0	28.15	648.8	Billion Yuan
Output	Exploitation occupation and destruction of land area (*EL*)	2.4×10^4	2.8×10^6	2	27679	5×10^7	Hectare
	Total carbon dioxide emissions (CO_2)	317	252.2	14.8	236.2	1554	10,000 tons
	Main energy production (*P*)	9576	16645	186	4254	100000	10,000 tons

Table 2
Descriptive statistics of variable data.

Var	Obs	Mean	SD	Min	Median	Max	obs0	mean(0)	obs1	mean(1)	mean-diff
CAP	300	362.12	243.14	20.00	288.00	1224	70	274.00	230	388.93	−114.93***
LAI	300	6.60	4.78	1.00	5.00	32	70	10.72	230	5.34	5.38***
KRI	300	0.36	0.13	0.00	0.00	1	70	0.37	230	0.36	0.01*
CEI	300	10.33	4.62	2.00	10.00	26	70	12.55	230	9.66	2.89***
EQI	300	63.16	20.24	3.00	63.00	98	70	63.29	230	63.12	0.17*
EPI	300	82.70	10.60	48.00	83.00	140	70	80.09	230	83.49	−3.41**
ISI	300	68.61	19.51	18.00	68.00	100	70	78.51	230	65.59	12.91***
TFP	270	1.02	0.11	1.00	1.00	2	70	1.01	230	1.02	−0.01*

Note: *, ** or *** indicates a significance level at 10%, 5%, and 1% respectively; 0 and 1 represent the control group (Control Group) and the treatment group (Treated Group), respectively.

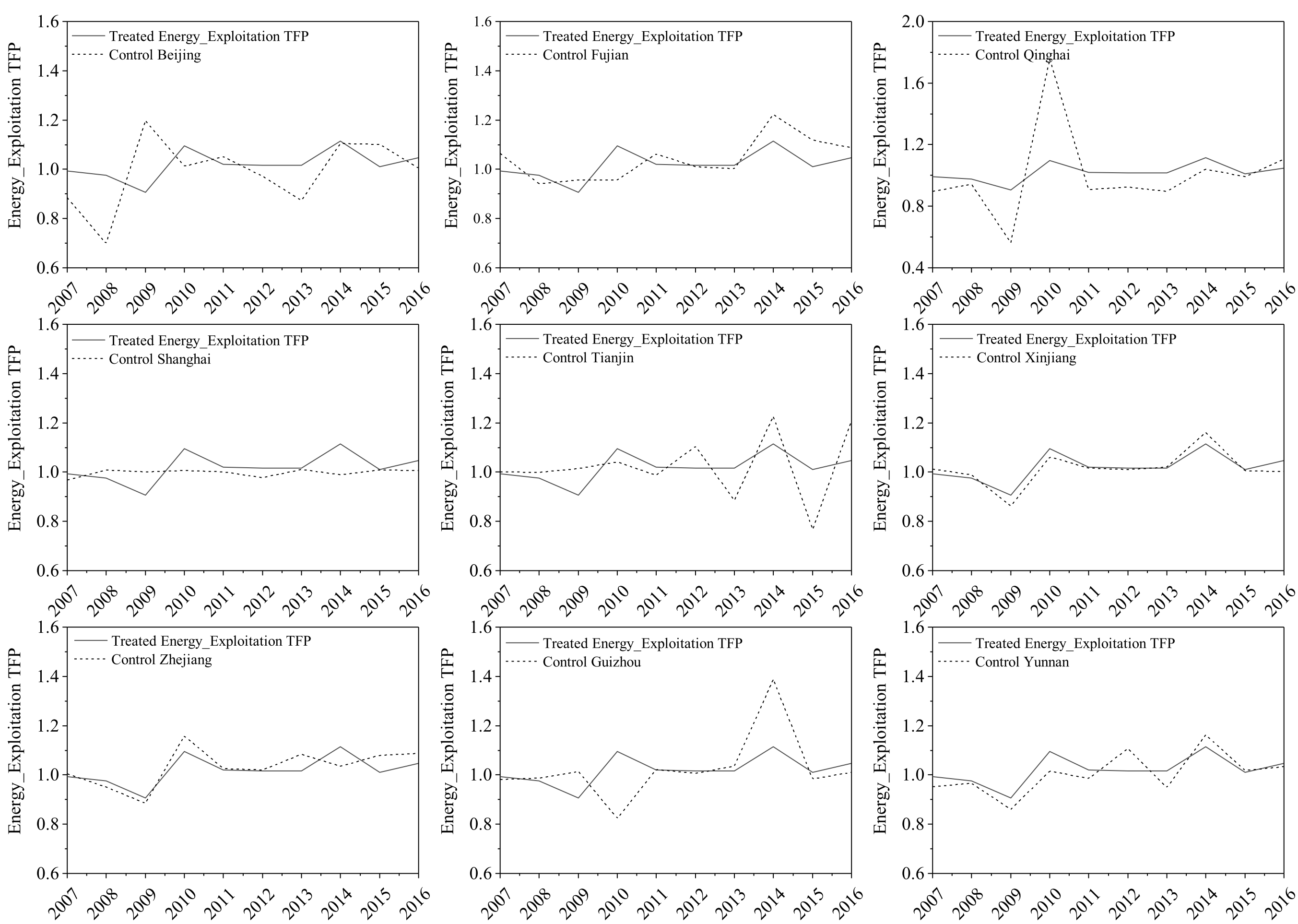

Fig. 2. Comparison of energy exploitation TFP in the Treated Group and Control Group Provinces from 2007 to 2016.

years. Initially, it is concluded that implementing the atmospheric policy improves energy exploitation TFP in the energy extraction and enrichment areas. Whether this is the case and the reasons for the synthesis can be verified and explained in section 5.

4. Empirical analysis of synthetic control method

4.1. Atmospheric implementation of energy exploitation

In the process of synthesis, each city in the control group will generate a weight. The city with high weight indicates that the result is more similar to the target's atmospheric policy implementation. In contrast, it indicates that the similarity is not high. This synthesizes a 'counter-fact' energy exploitation enrichment province, and the city affected by atmospheric policy, and its curve almost coincides with the real curve before the policy occurs. Since the purpose of the 'counter-factual' curve synthesis is to simulate the situation of the target area where the policy is not implemented, the difference between the real curve and the composite curve after the policy implementation occurs, the effect is explained. If there is no significant difference between the two curves, it means that the policy implementation has no obvious effect. In contrast, it shows that the reform has played a certain definite role. Figs. 3–6 show the results for 21 synthetic target areas.[3] Fig. 3 is the synthetic energy exploitation province TFP and the actual energy extraction TFP result for five provinces, namely Guangdong, Hainan, Hebei, Jiangsu, and Shandong; Fig. 4 is the TFP results for synthetic energy exploitation TFP and actual energy exploitation in the six provinces of the central region comprising Anhui, Henan, Hubei, Hunan, Jiangxi, and Shanxi. Fig. 5 shows the results of TFP and actual energy exploitation TFP in the provinces of Guangxi, Inner Mongolia, Ningxia, Shaanxi, Sichuan, and Chongqing. Fig. 6 displays the results of synthetic energy exploitation TFP and the actual energy extraction TFP in the northeast region; it includes Heilongjiang, Jilin, and Liaoning. Among them, the vertical dotted line represents the year in which the policy is implemented, and the observation of the trend of the two curves before and after the vertical dotted line can be concluded. The solid line represents the real exploitation of energy-rich regions during the period from 2007 to 2016, and the dotted line indicates the synthesis of energy-rich exploitation area of energy TFP. Overall, there is a certain spatial heterogeneity in the impact of current atmospheric policies on energy. That is, the implementation of atmospheric policies in some regions can improve their energy exploitation TFP and optimize allocation of energy resources, but due to the different functions of atmospheric policy implementation in various regions, not all policy implementations can encourage the promotion of total factor productivity.

4.1.1. The eastern region

In the eastern regional synthesis results (Fig. 3), the straight lines and dashed lines almost overlap before the vertical dashed lines in Guangdong, Hebei, Jiangsu, and Shandong provinces, indicating that the synthetic policy simulation results are better. After the vertical dashed line, energy extraction in Guangdong, Hebei, and Jiangsu provinces TFP curve compositing target energy extraction zone TFP under the curve. Fig. 3 illustrates that Shandong is the actual energy extraction TFP curves energy exploitation in the synthesis of the target region, and the curve of the TFP crosses. From Fig. 3 results, it can be concluded that after the energy exploitation is enriched in the eastern provinces of Guangdong, Hebei, and Jiangsu, the implementation of the 'Atmosphere Ten Articles' policy, the promotion effect of its energy exploitation TFP is not obvious, but the efficiency of energy exploitation is reduced. The policy measures implemented in Shandong have a lagging effect on the energy exploitation TFP.

4.1.2. The central region

In the synthetic results of the central region (Fig. 4), the straight lines and the dotted lines almost overlap before the vertical dashed lines in the six provinces of Anhui, Henan, Hubei, Hunan, Jiangxi, and Shanxi, indicating that the synthetic policy simulation results are better. After the vertical dashed line, the actual energy extraction target area Henan, Hunan, and Jiangxi provinces TFP curve compositing target energy extraction zone TFP under the curve; and Fig. 4 shows that Anhui and Shanxi provinces is the actual energy extraction TFP curve Synthesis Above the target area energy exploitation TFP; the actual energy exploitation TFP curve in Hubei area has a cross-change in the TFP of energy exploitation in the synthetic target area. From Fig. 4 results, it can be concluded that the influence of the 'Atmosphere Ten Articles' policy has improved the energy exploitation TFP of Anhui and Shanxi, and the promotion of TFP for energy exploitation has been remarkable. The results are optimized to improve the allocation of energy resources, but the effects of atmospheric policies in Henan, Hubei, and Hunan have a lagging effect.

4.1.3. The western region

In the western regional synthesis results (Fig. 5), the straight lines and the dotted lines almost overlap before the vertical dotted lines in Gansu, Shaanxi, and Sichuan provinces, indicating that the synthetic policy simulation results are better. After the vertical dashed line, the actual energy extraction target area Gansu, Sichuan, and Guangxi TFP curve compositing target energy extraction zone TFP under the curve; Chongqing is the actual energy extraction TFP curve energy exploitation in the synthesis of the target region TFP above; there is a change in Inner Mongolia and Ningxia actual energy extraction TFP curve compositing target area energy extraction TFP intersects the curve; Shaanxi and Gansu's curves are more overlapping portions, which show that embodiments of energy policy atmospheric did not have a significant impact. From Fig. 5, it can be concluded that the energy exploitation TFP has been improved in Chongqing by the influence of the 'Atmosphere Ten Articles' policy in the seven provinces, and the promotion effect on its energy exploitation TFP has been remarkable, achieving certain results and optimization. The allocation of energy resources and the impact of atmospheric policies in Inner Mongolia and Ningxia have a lagging effect, while the implementation of atmospheric policies in Gansu and Shaanxi is not obvious.

4.1.4. The northeast region

In the synthetic results of the northeast region (Fig. 6), the straight lines and the dotted lines almost overlap before the vertical dotted lines in the Heilongjiang, Jilin, and Liaoning provinces, indicating that the simulation results for the synthetic policy are better. After the vertical dashed line, and energy extraction for Heilongjiang, the Jilin actual target area TFP curve compositing target energy extraction zone TFP under the curve; there is a change in the actual energy exploitation TFP curve of Liaoning compositing target area energy extraction TFP intersects the curve. From Fig. 6 results, it can be concluded that the influence of the 'Atmosphere Ten Articles' policy on energy extraction and enrichment area has not improved the energy exploitation TFP in Heilongjiang and Jilin, and the promotion effect of energy exploitation TFP is not significant. The effect of atmospheric policy in Liaoning has a lagging effect.

4.2. Validity and robustness test of synthetic results

4.2.1. Placebo robustness test

In this study, we use the placebo test to test the validity and robustness of SCM on the synthetic results (Abadie and Gardeazabal, 2003). The basic idea of the placebo test is to select a provincial administrative district that is not a target area and has not been designated as an energy extraction enrichment area during the measurement period, and perform the same synthetic analysis, such method is similar

[3] We can see the different regional division results at http://www.stats.gov.cn/ztjc/zthd/sjtjr/dejtjkfr/tjkp/201106/t20110613_71947.htm.

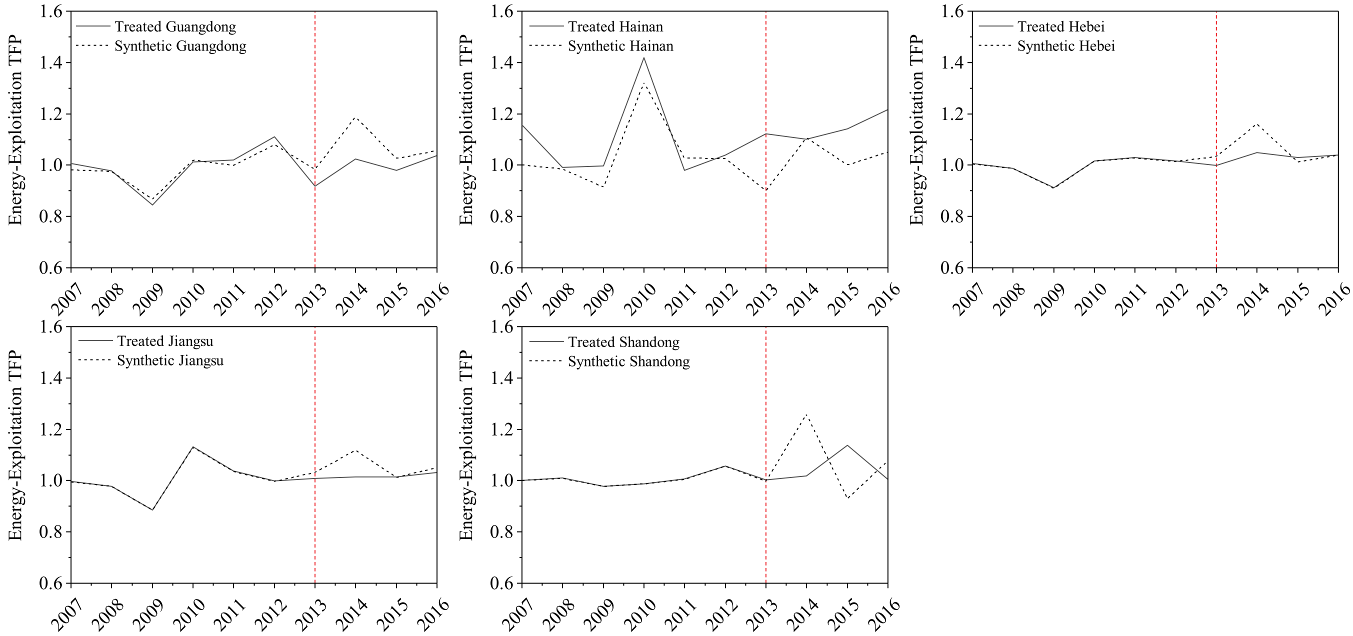

Fig. 3. Comparison of actual and synthetic changes of energy exploitation TFP in the eastern region.
Note: The vertical dotted line is the year of policy implementation, the horizontal dotted line is the synthetic energy exploitation TFP, and the solid line is the actual energy exploitation TFP, the same below.

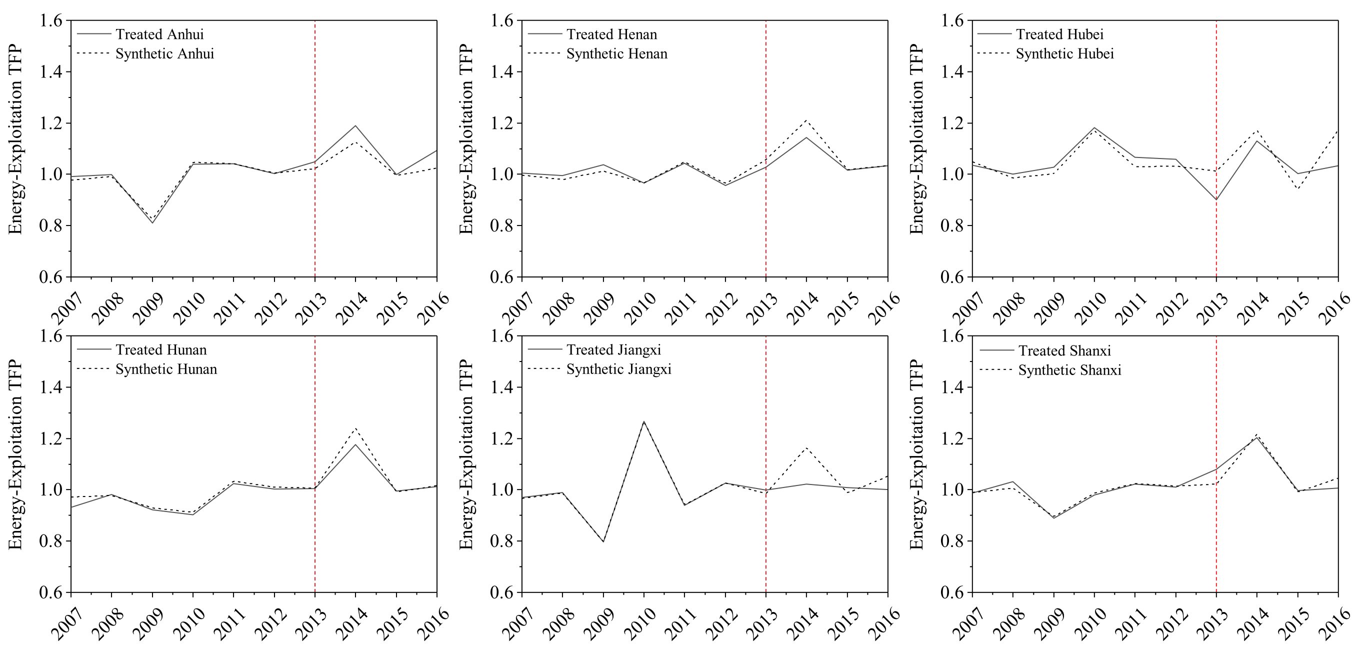

Fig. 4. Comparison of actual and synthetic changes of energy extraction TFP in the central region.

with the training/test strategy (Wu et al., 2013, 2018; Lu et al., 2016). It is necessary to observe if there is a significant difference from the actual situation after the synthesis. This is mainly because the selected provinces are not the same as the real SCM target areas. Therefore, it is consistent with the SCM's synthesis effect on the control group and with the control group's actual energy exploitation trend of TFP change. Since the results of the synthesis show that the implementation of atmospheric policies in the east, central, west, and northeast regions can increase the TFP, consistent with the idea of placebo selection, this study examines the synthesis of energy exploitation TFP in the control group. Fig. 7 presents the results.

Since the synthetic control method uses macro data to estimate policy effects, the uncertainty caused by the macroscopic effect of micro-data estimation is avoided. However, it is impossible to determine if the constructed synthetic control group can fit the potential change path of the processing group appropriately, that is, the 'counterfactual' state, so a certain degree of uncertainty in estimating the parameters continues. Fig. 7 shows the results of the placebo test conducted in nine provinces. The true value of the energy extraction TFP is basically consistent with its composite value, indicating that SCM fits the growth path of the two

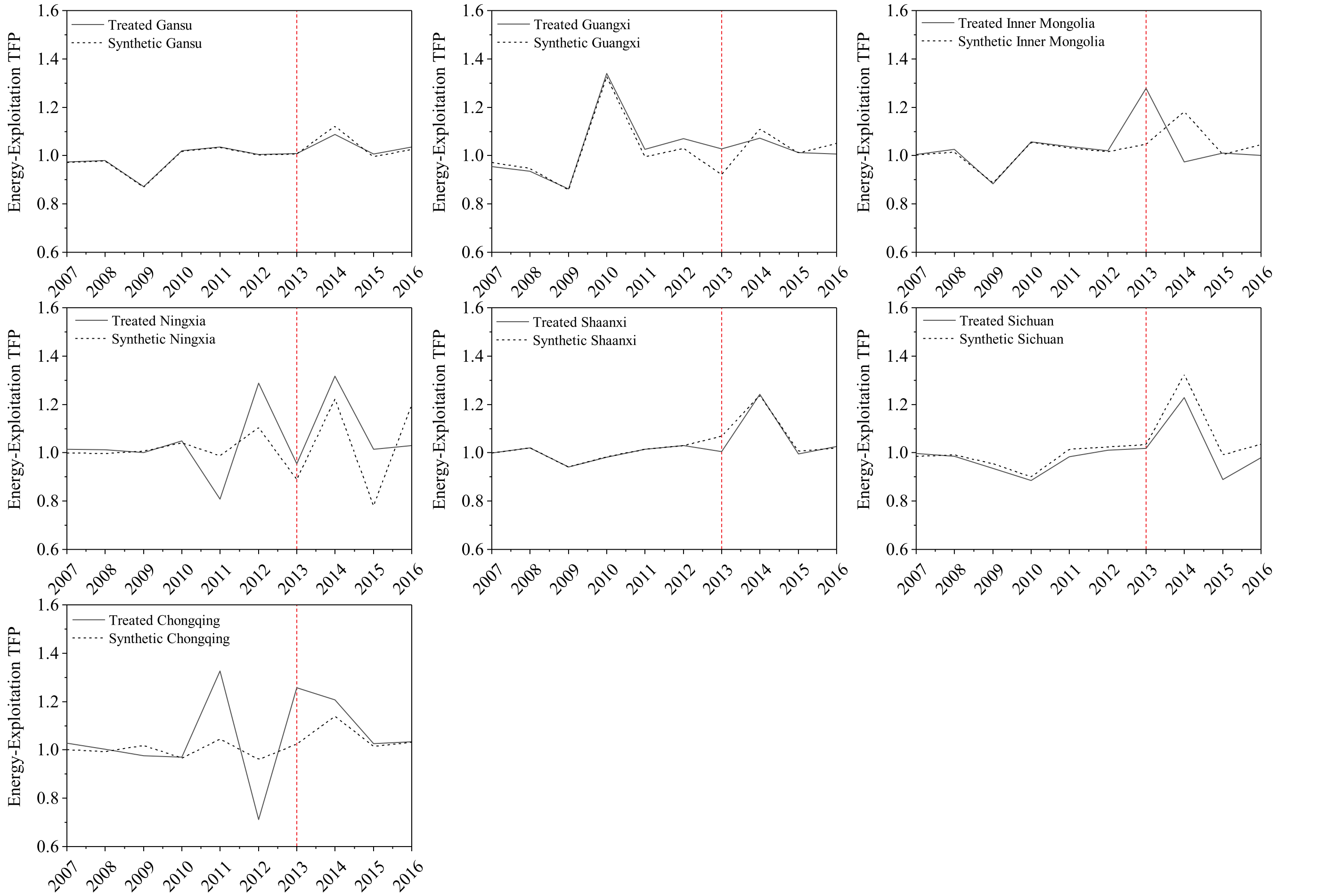

Fig. 5. Comparison of actual and synthetic changes of energy extraction TFP in the western region.

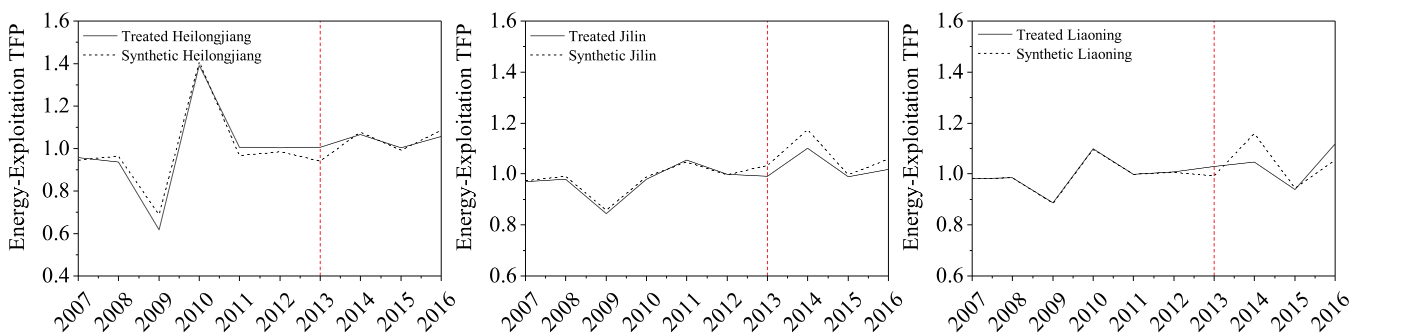

Fig. 6. Comparison of actual and synthetic changes of energy extraction TFP in the northeast region.

appropriately and its fitting is in the atmospheric policy, before and after the implementation has not mutated. Thus, the inspection certificate of other treatments in provinces' energy extraction TFP is affected by the implementation of the atmospheric policy, rather than the other causal factors.

4.2.2. Validity test

Further, from the results of the validity test (Fig. 8 and Table 3), the root mean squared percent error (RMSPE) results of the energy extraction enrichment area are shown in Table 3, which are much higher than their corresponding similar control analysis units (Fig. 8), indicating synthetic control. The empirical results for the implementation of the expansion policy to promote economic growth are effective. It is worth noting that according to the principles of synthetic control law, the greater the weight of provinces in the control group, the more similar the provinces are to the target area. Therefore, a similar control group in the placebo method selects provinces with synthesis rights greater than the mean. Based on the results of the effectiveness of the permutation test (Fig. 8), the black solid line in Fig. 8 represents the prediction error of the target area, and the grey dashed line represents the prediction error of the stochastic control unit, which can clearly be observed in the black reality of most of the target research provinces. The line is higher than the grey dotted line, indicating that if a control unit is randomly selected for estimation, it is indeed a small probability event to obtain results

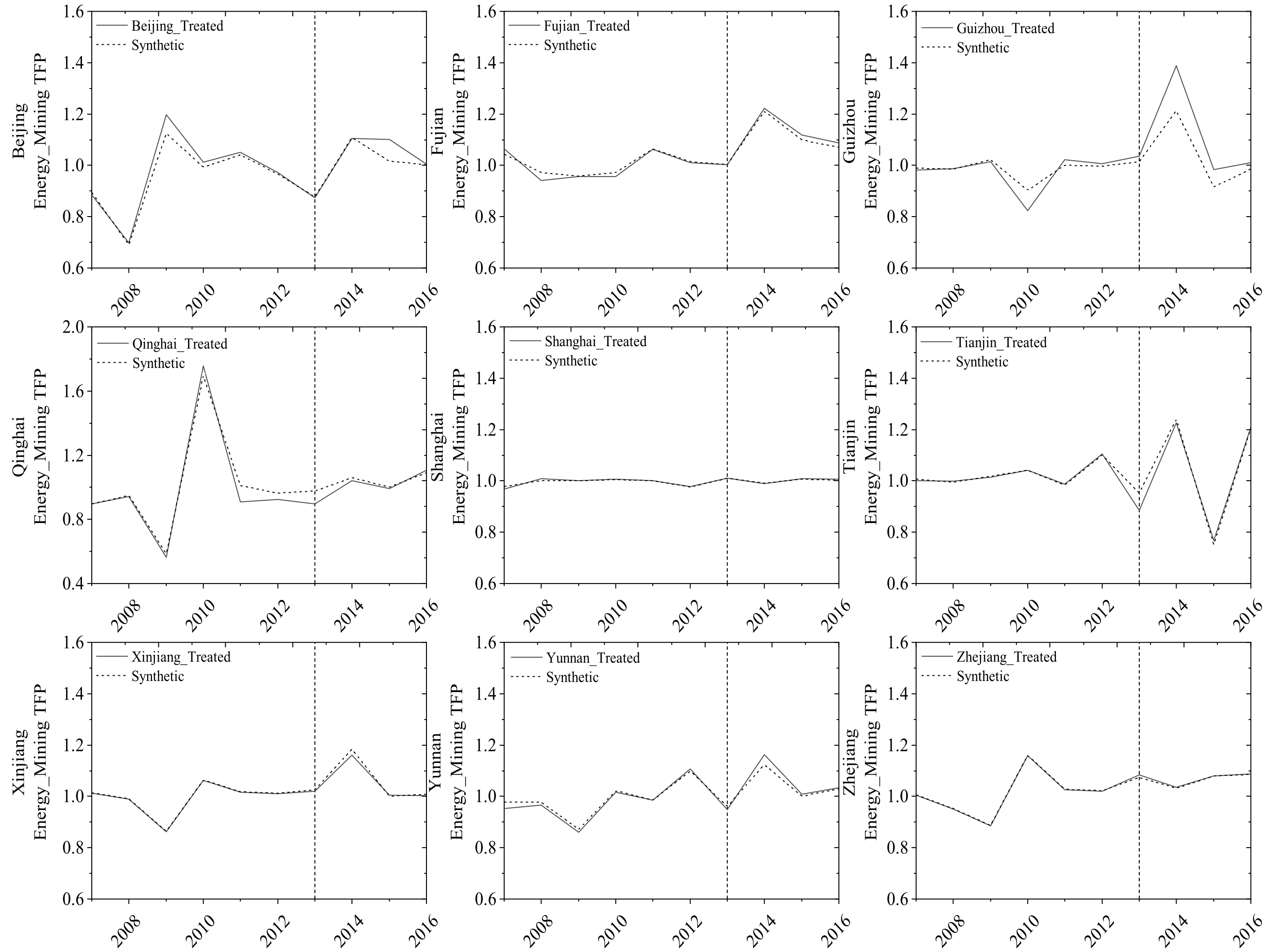

Fig. 7. Comparison of estimated results of energy exploitation TFP synthesis in the control groups.

consistent with the target analysis unit, indicating that there is a significant difference between the synthetic residual of the target analysis unit and the random control analysis unit. That is to say, it is effective to use the synthetic control method to analyse the implementation of the atmospheric policy and promote energy exploitation TFP in the energy exploitation enrichment areas.

5. Verification of mechanism

Earlier results show that in 2013, implementation of the 'Atmosphere Ten Articles' policy significantly promoted the TFP of energy extraction in some provinces, and different regions have different characteristics. Therefore, this study further examines how atmospheric policies can promote or reduce energy exploitation TFP in different regions and how to determine the mechanism of atmospheric policy affecting energy exploitation TFP. To this end, first, this part is based on Fig. 1 to set the panel Tobit model of the atmospheric policy affecting energy exploitation TFP; then, China's overall and grouped data are used to verify and compare different mechanisms; finally, the empirical results are explained.

5.1. Mechanism model

To further test the hypothetical action path shown in Fig. 1, the following model is set to test Fig. 1:

$$\begin{aligned} TFP_{i,t} = {} & \eta_0 + \eta_1 Policy_{i,t} + \eta_2 Policy_{i,t} \times Demo_{i,t} + \eta_3 Policy_{i,t} \times Industry_{i,t} \\ & + \eta_4 Policy_{i,t} \times Market_{i,t} + \eta_5 Demo_{i,t} + \eta_6 Industry_{i,t} + \eta_7 Market_{i,t} \\ & + \eta_8 Control(variables)_{i,t} + u_{i,t} \end{aligned} \tag{12}$$

In the above formula, *TFP* is the dependent variable, representing the provincial energy extraction TFP changes. *Policy* is the independent variable, indicating if the energy-rich region for the implementation of exploitation policy dummies atmosphere, from 2013 onwards Assignment Policy = 1. Previously assigned Policy = 0 before 2013; *Demo*, *Industry*, and *Market* are the three action mechanism variables of the atmospheric policy, which are the regional economic linkages, namely demonstration effect, coordination degree of industrial division of labour, and the unified coordination degree of the energy market. Control (*variables*) is the control variable in this study, which mainly includes innovation ability, urbanization rate, openness, educational level, foreign direct investment, population density, and fiscal expenditure.

5.2. Basic variables

By referring to Wang et al. (2017) in the study of energy production and its subsidy relationship calculating technology innovation method, we used the stochastic frontier model analysis method to calculate demonstration effect (*demo*). The regional economic linkage, that is, *Demo* is expressed by the lag term of technological innovation, and the

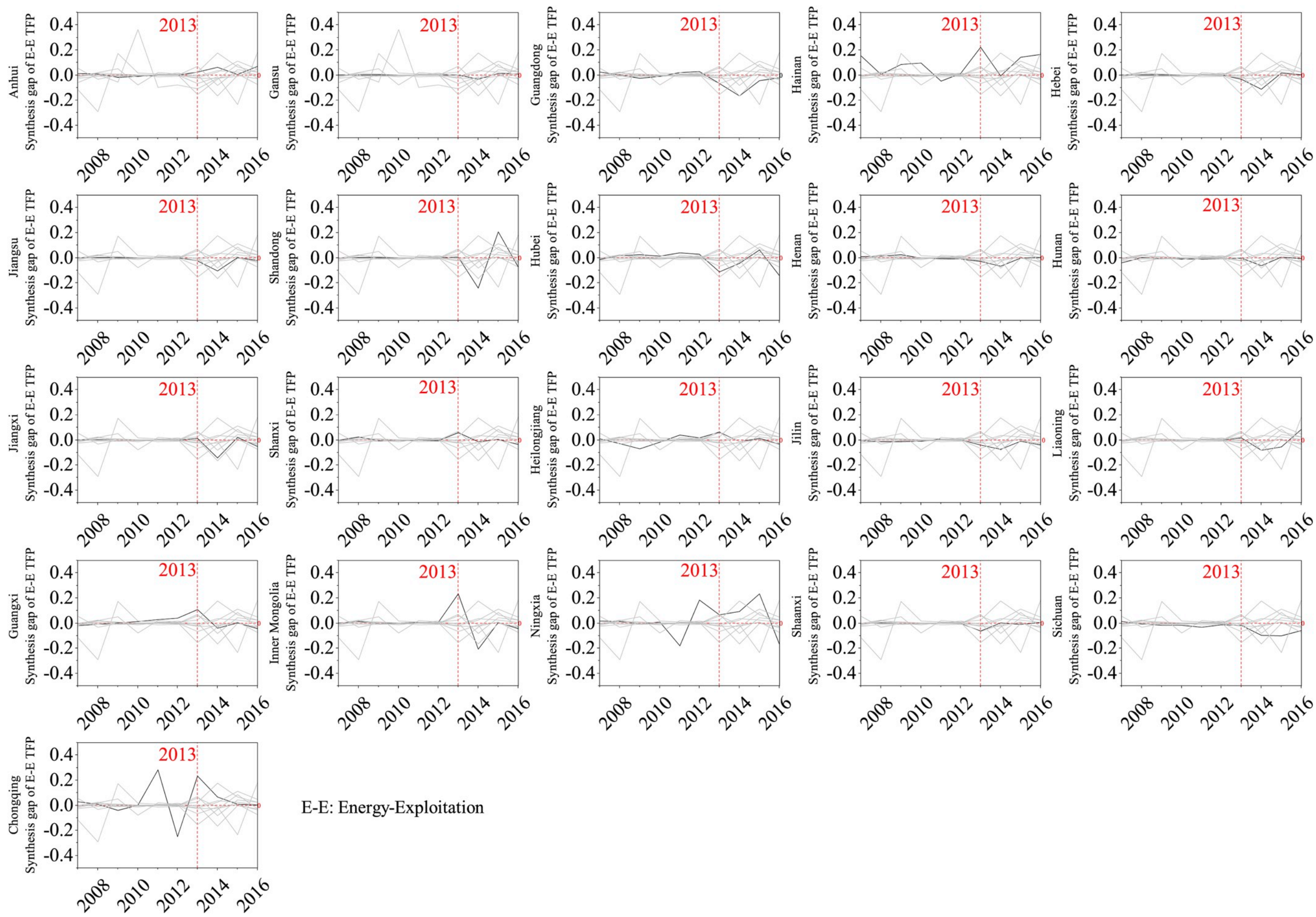

Fig. 8. Arrangement test method – Forecast error distribution of provincial, municipal, and control groups in the target-processing group.

Table 3
RMSPE statistics.

Province	Guangdong[1]	Hainan[1]	Hebei[1]	Jiangsu[1]	Shandong[1]	Anhui[2]	Henan[2]
RMSPE	0.0216978	0.084622	0.000059	0.000021	0.000786	0.009502	0.012671
Province	Hubei[2]	Hunan[2]	Jiangxi[2]	Shanxi[2]	Heilongjiang[4]	Jilin[4]	Liaoning[4]
RMSPE	0.0239851	0.017954	0.001702	0.011283	0.036474	0.009041	0.000013
Province	Gansu[3]	Guangxi[3]	InnerMongolia[3]	Ningxia[3]	Shaanxi[3]	Sichuan[3]	Chongqing[3]
RMSPE	0.0000023	0.023377	0.005927	0.105279	0.000708	0.017766	0.155169

Note: 1, 2, 3, and 4 represent the eastern region, the central region, the western region, and the northeast region, respectively.

calculation formula is:

$$Demo_{i,t} = \mathrm{E}\left[\left(exp\left(Y^*_{i,t}\right)|\gamma_{i,t}, Var_{i,t}\right)\right] \Big/ \mathrm{E}\left[\left(exp\left(Y^*_{i,t}\right)|\gamma_{i,t}=0, Var_{i,t}\right)\right] \tag{13}$$

$$Y^*_{i,t} = \phi_0 + Var_{i,t}\phi + \vartheta_{i,t}, \vartheta_{i,t} = v_{i,t} - \gamma_{i,t} \tag{14}$$

where $Y^*_{i,t}$ is the regional GDP; $Var_{i,t}$ are labour, capital stock, and time variable; $\vartheta_{i,t}$ is the residual term; $v_{i,t} - \gamma_{i,t}$ is the random disturbance term, where $v_{i,t}$ is a random variable, and $\gamma_{i,t}$ is the technical inefficiency interference term for technical efficiency loss.

The division of degree of coordination of industrialization (*Industry*) represents the energy-rich exploitation area *i* in the first *t* years; the remaining 20 industrial division of responsibilities in the provinces is calculated as Eq. (15):

$$Industry_{i,t} = \sum_{j=1}^{21} \Delta energy_{i,t} \tag{15}$$

where $\Delta energy_{i,t}$ denotes *t* of energy-rich exploitation area *i* and *j* between the relative changes in the employment of the energy industry are based on the methods proposed by Liu and Wu (2017) and Chen and Tang (2016) using the pairing method to summarize the degree of industrial division of labour caused by the employment of energy exploitation enrichment areas.

The market's unified coordination degree (*Market*) uses coal (power coal), petroleum (gasoline, diesel and civil liquefied petroleum gas), and natural gas (civil gas and industrial natural gas) transaction prices to calculate relative price differences, drawing on Liu and Wu (2017) calculation formula:

$$Market_{i,t} = 1 \Big/ \sum_{j=21}^{21} \Delta price_{ij,t} \tag{16}$$

where $\Delta price_{ij,t}$ represents the relative price difference formed by multiple energy products trading between *i* and *j* in the energy exploitation

Table 4
Benchmark regression results.

TFP	(1) Pols	(2)Pantob	(3)xttobit	(4)	(5)	(6)
Policy	−0.158(0.17)	−0.158(0)	−0.158(0.165)		−0.68***(0.188)	
Demo	0.594***(0.07)	0.498**(0.216)	0.594***(0.07)	0.729***(0.06)		
Industry	0.002(0.004)	0.002 (0.004)	0.002(0.004)	0.0024(0.004)	0.006(0.005)	0.0048(0.005)
Market	−0.115**(0.06)	−0.123***(0.038)	−0.115**(0.05)	−0.0781(0.058)	−0.203***(0.074)	−0.144*(0.075)
Policy × *Demo*	0.164(0.149)	0.167(0.266)	0.164(0.144)	−0.0097(0.042)	0.721***(0.158)	0.138***(0.052)
Policy × *Industry*	−0.003(0.005)	−0.0037(0.0057)	−0.003(0.005)	−0.0043(0.005)	−0.00801(0.006)	−0.0113*(0.006)
Policy × *Market*	0.056 (0.112)	0.0627(0.068)	0.056(0.108)	0.0708(0.097)	0.0654(0.135)	−0.121(0.125)
Policy lag 1				0.065***(0.024)		0.0730**(0.03)
Demo lag 1					0.151**(0.074)	0.24***(0.077)
Constant	0.306***(0.1)		0.306***(0.092)	0.109(0.0906)	0.939***(0.107)	0.96***(0.11)
Control	✓	✓	✓	✓	✓	✓
Hausman		0.88(p = 1.00)	RE	RE	RE	RE
Obs	210	210	210	189	189	189

Note: Standard errors in parentheses: ***P < 0.01, **P < 0.05, *P < 0.1; model (1) is ***xtreg*** in the ordinary panel regression calculation result of the command. Model (2) uses Honoré (1992) and Honoré et al. (2000) prepared ***pantob*** estimated panel Tobit fixed effect results. Model (3) is ***xttobit*** estimated panel Tobit random effect results; panel Tobit fixed effect and random effect Hausman test results are 0.88, whose p value is 1; thus, accepting the null hypothesis that the random effect is better than the fixed effect. Models (4) to (6) are the panel Tobit random effects for model estimation.

enrichment area in the *t*-th year. The data are mainly from the Energy Comprehensive Database price base database (http://db.energy.ckcest.cn/price/?id=954417).

5.3. Results

To verify the specific impact of the implementation of the atmospheric policy on energy exploitation TFP in different energy extraction and enrichment areas, this study divides them into the northeast (three provinces) and eastern regions (five provinces) following Section 3.3. Table 4 shows the specific impact degree and statistics for implementing the atmospheric policy on the energy exploitation TFP in the different energy extraction and enrichment areas. The results show that there is a negative correlation between atmospheric policy and energy exploitation. From the perspective of the three mechanisms (Fig. 1), the demonstration effect of regional economic linkages contributes to the promotion of energy exploitation TFP ($\alpha = 0.594$) and a significant pass at the 1% level. There is a significant negative correlation between the degree of coordination of the energy market and the TFP of energy extraction ($\alpha = -0.115$), passed the test at 5% level, which indicates that the energy market price under atmospheric policy cannot promote energy exploitation TFP effectively. Specifically, representation of the degree of coordination of the energy market shows that there is a certain degree of distortion in energy prices.

From the perspective of lag, model (4) shows that the lag of the atmospheric policy can effectively improve the energy exploitation TFP, and model (5) shows that technological innovation can improve the energy exploitation TFP, whether it is lagging or current, which verifies the regional economic relationship of Fig. 1 to some extent, that is, demonstration effect. Model (6) represents the double lag of the implementation of the atmospheric policy and technological innovation. In summary, implementation of the atmospheric policy has not effectively improved energy efficiency in the current period. However, it takes time to play a role, and the model estimates show that atmospheric policy and technological innovation are more conducive to improving energy exploitation TFP, but industrial division of labour and the energy market price mechanism find it difficult to promote energy exploitation TFP.

In conclusion, the current impact of the 'Atmosphere Ten Articles' policy has not affected the TFP of energy exploitation, but the hysteresis effect is significantly positive. The main reasons are as follows:

(1) Although China has achieved significant development in energy exploitation, it has not yet developed a scale, and thus the channels of influence of atmospheric policy are affected.

(2) Although energy exploitation TFP has improved, construction of the energy market needs to be improved, and this can be seen from the model (3). In energy exploitation, transportation facilities for the strategic reserves need to be improved, and degree of coordination is low in the energy market. As a result, the energy extraction industry is not efficient in energy transmission and has high operating costs. Eventually, the impact of unified coordination of the energy market on the energy exploitation TFP is significant. Moreover, the price mechanism prevailing in the energy market has not really affected energy exploitation, as the transmission channel is subject to government regulation, and the regulation channel lag is affected by the energy price pricing mechanism, which ultimately affects the unified coordination of the energy market.

(3) The implementation of the atmospheric policy did not have the corresponding laws and regulations to prevent carbon dioxide/GHG emissions, so the feedback on energy exploitation TFP is not obvious. At present, laws and regulations applicable to the energy exploitation industry are not perfect, especially in the areas of long-distance transportation and provincial distribution. Except for regulations that concern safety, technology, and environmental protection, the Ministry of Construction has ministerial regulations on energy development, and laws and regulations for

Table 5
Sub-regional regression results.

TFP	(1)Northeast	(2)Eastern	(3)Central	(4)Western
policy	0.309** (0.146)	0.0848** (0.0384)	−0.421(0.41)	−0.22 (0.277)
demo	1.442*** (0.117)	0.401*** (0.0754)	0.637*** (0.13)	0.452*** (0.137)
industry	0.0184 (0.0163)	−0.0305*** (0.011)	0.0162 (0.0101)	0.000375 (0.0092)
market	−0.180 (0.309)	−0.156** (0.0773)	−0.0243 (0.154)	−0.240 (0.176)
policy × *demo*	−0.385 (0.358)	−0.0337 (0.309)	0.671** (0.312)	0.113(0.243)
policy × *industry*	−0.00034 (0.016)	0.000806 (0.0099)	−0.0361** (0.0156)	0.00614 (0.0109)
policy × *market*	0.122(0.463)	−0.197(0.192)	−0.228(0.46)	0.382(0.254)
Constant	−0.345 (0.415)	0.879*** (0.149)	0.164(0.221)	0.367* (0.209)
Control	✓	✓	✓	✓
FE/RE	RE	RE	RE	RE
Obs	30	50	60	70

Note: Standard errors in parentheses; ***p < 0.01, **p < 0.05, *p < 0.1. Models (1)–(4) are estimated using the panel Tobit random effect model.

economic supervision are almost entirely absent, which is not conducive to the establishment of the cooperative relationships between the energy exploitation industry and the mainstream enterprises.

5.4. Discussion

Table 5 reports the processing results for the 21 provinces. Model (1)-model (4) are the estimated results of the eastern, central, and western regions of the northeast, and the estimated test results show that the impact of implementing the 'Atmosphere Ten Articles' policy are inconsistent in different regions. The atmospheric policies promote the energy exploitation TFP in the northeast and the eastern regions, but the central and western regions show an inverse relationship with the energy exploitation TFP, which indicates that regions with higher economic development level implement the policies. Atmospheric policy seems more beneficial to improve energy exploitation TFP and optimize energy exploitation structures. From the estimation results of the three mechanisms, technological innovations in the northeast region can effectively improve the energy exploitation TFP in the eastern, central, and western regions. This shows that the atmospheric policies can promote energy exploitation TFP in different regions through technological innovation, if the central region passes a policy in a timely manner, technological innovation can improve energy exploitation TFP significantly. Although the degree of industrial division and energy market uniformity in the eastern region significantly affects energy exploitation TFP, the estimation results correlate negatively with energy exploitation. The estimation results of the interaction term show that the estimation results of the three mechanisms of action of atmospheric policy are not significant in the northeast, eastern, and western regions. From the sub-regional results, the spatial heterogeneity of the impact of atmospheric policy is obvious on energy exploitation TFP, which further verifies the SCM's assessment of atmospheric policy.

The implementation of atmospheric policies can positively promote energy exploitation TFP in the northeast and eastern regions. This shows that implementation of the atmospheric policy can achieve the effect of simultaneously simulating the surrounding areas, and the northeast region can achieve economic development through the eastern region. Complementary resources reduce environmental pollution, while achieving internal cost internalization. After the introduction of the 'Atmosphere Ten Articles' in the eastern and northeast regions, a number of policies and regulations were issued, especially in the Beijing-Tianjin-Hebei region. This driving and demonstration effect has improved the energy exploitation TFP to a certain extent, while reducing environmental pollution and promoting technological innovation. However, due to the natural environment and economic geography, the central and western regions show no obvious response to the 'Atmosphere Ten Articles' policy, so they can only improve energy extraction efficiency through technological innovation.

In summary, we find that the effects of various mechanisms are quite different. The regional economic linkages and demonstration effects resulting from technological innovation can significantly reduce the impact of implementation of the atmospheric policy on energy exploitation TFP; industrial division of labour can positively promote energy extraction. However, the TFP estimates are not significant, and the degree of coordination in the energy market is just the opposite. In

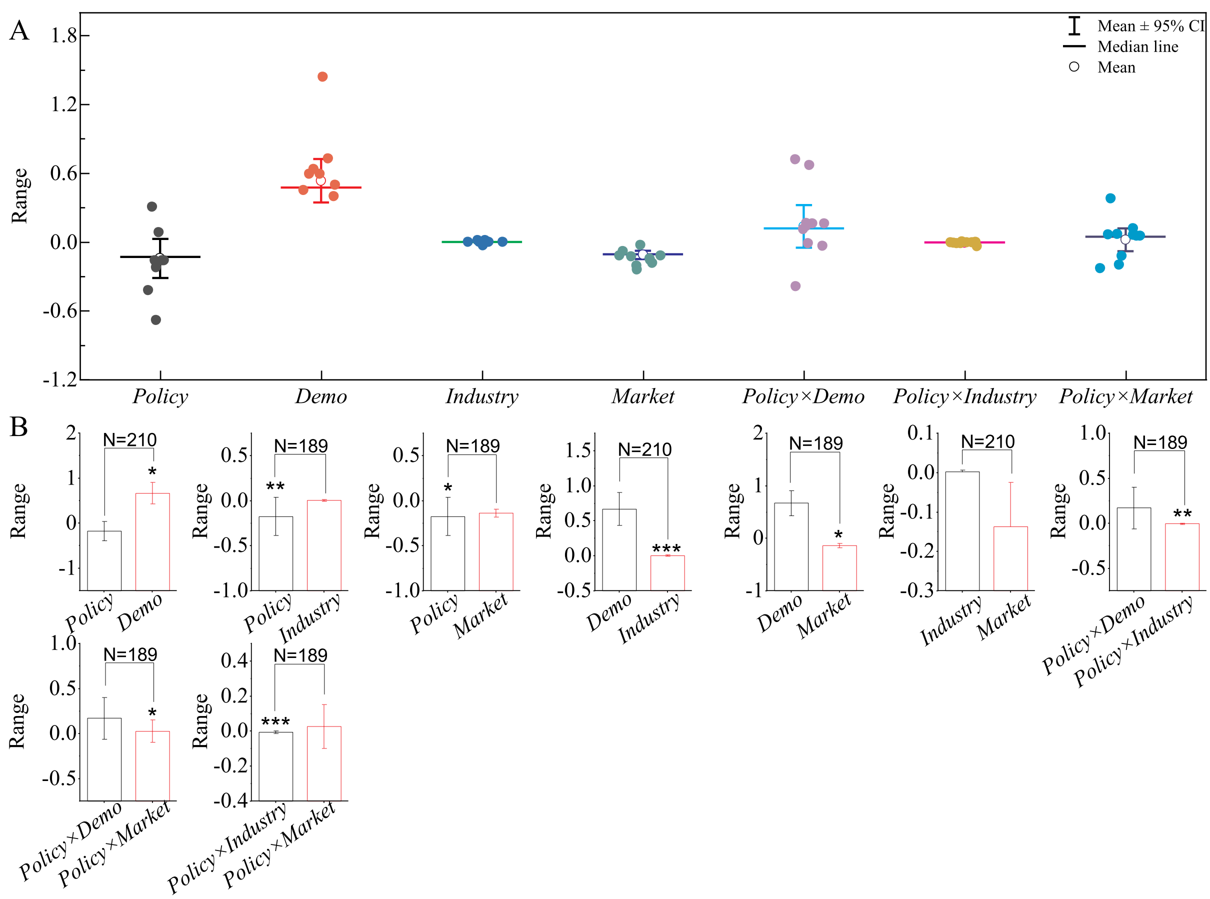

Fig. 9. Statistical characteristics of coefficient results based on panel TOBIT model estimation.
Note: A is a scatter plot of the estimated results, showing the mean and its mean ± 95% interval change. B shows the mean value of the estimated results of the basic variables and their error changes. * indicates the significant correlation between the two. ***p < 0.01, **p < 0.05, *p < 0.1; N represents the number of samples. The line is 5% error line in Fig. A and Fig. B.

addition, the three mechanisms of action also have different effects in different regions. The regional economic linkages, namely the demonstration mechanism brought about by technological innovation has a heterogeneous impact on TFP growth in different regions, while industrial division of labour and unified coordination of energy markets are effective and promote energy exploitation TFP in the northeast, eastern, central, and western regions.

5.5. Robustness analysis

In this paper, considering the estimation results of Tables 4 and 5, the statistical results are used to analyse the robustness of the atmospheric policy to the TFP. The results are shown in Fig. 9A and B. The model estimation results before and after the control variables show that the variable *Industry* and variable *Market* and the variable interaction coefficient *Policy*×*Industry* coefficient have less fluctuation, and the coefficients are all less than 0. From Fig. 9B, it is shown that the relationship between atmospheric policy and energy exploitation TFP is still very stable and significant. It can be known from the final report results of Fig. 9 that the estimation results of the variable *Industry* and the *Market* and the variable interaction item (*Policy*×*Industry*) are very robust. However, the coefficient of estimation of the dummy variables of atmospheric policy is relatively scattered, and the impact of technological innovation is generally positive.

6. Conclusion

The implementation of 'Atmosphere Ten Articles' plays a crucial role in energy production and consumption. In this study, the SCM is used to simulate and compare the TFP change path in the energy exploitation and enrichment areas during 2007–2016. The results show that the atmospheric policy contributes to energy extraction TFP growth under the SCM method in Shandong, Anhui, and Shanxi. However, at the same time, the impact of atmospheric policy in most regions is not obvious, while the lagging effect of atmospheric policy is evident in Gansu, Shaanxi, Liaoning, and other places. On this basis, to provide deeper insights into how the atmospheric policy affects energy exploitation TFP, this study proposes three action mechanisms and uses panel Tobit model to test them. The test results show that the implementation of atmospheric policy did not improve TFP during 2007–2016. However, it takes time to work, and the model estimation results show that 'Atmosphere Ten Articles' and technological innovation are more conducive to improving energy exploitation TFP, but it is difficult for industrial division of labour and the energy market price mechanism to promote energy exploitation TFP; the impact of atmospheric policy varies in different regions. The impact of atmospheric policies can significantly promote energy exploitation TFP in the northeast and the eastern, but the central and the western show an inverse relationship with energy exploitation TFP.

The study results on the impact of implementation of the atmospheric policy on energy extraction TFP have the following implementations for regional energy production supply chains:

(1) Technological innovation has a significant impact on regional economic linkages and demonstration effects; thus, energy exploitation needs to focus on technological advancement or innovation, and the implementation of green exploitation technology would enable the energy industry to enter a sustainable development path and ensure energy security. The research results show that technological innovation in the energy exploitation industry has a certain lag effect. The timely adoption and implementation of new technologies and new equipment can alleviate the hysteresis caused by the implementation of technological innovation. The introduction of new technologies and new equipment for energy exploitation contributes to environmental pollution and ecological damage caused by energy exploitation, and to some extent, it can improve the TFP of energy extraction.

(2) We will give full scope to the positive role of the industrial division of labour, plan the layout of the energy industry in detail through industrial division of labour, and give play to the positive functions of industrial gradient transfer. The energy industry is inconsistent in the eastern, central, western, and northeast regions. The study results indicate that industrial division in the eastern region affects energy exploitation TFP, but the other regions are not affected by the energy exploitation TFP, which requires the central region to play a key role. To fulfil the function of rationally arranging the energy industry, the central and western regions actively undertake energy exploitation, and the eastern region continue to play an active role in attracting investments in the energy industry.

(3) The unified construction of the energy market needs to actively play the price mechanism and reduce distortions. The characteristics of industrial layout and resource endowment determine the energy prices in different regions, establish a floating mechanism for energy market prices, and reflect the role of energy exploitation TFP and atmospheric policies through prices, providing ideas for environmentally sustainable development.

(4) The mechanisms of action vary by region, and the functions of the top-level design are used to cross-link different mechanisms according to local conditions in different regions, thus avoiding the negative effects caused by a single mechanism.

CRediT authorship contribution statement

Jiachao Peng: Methodology, Software, Writing - original draft. **Jianzhong Xiao:** Conceptualization, Writing - review & editing. **Lian Zhang:** Data curation, Visualization, Investigation. **Teng Wang:** Data curation, Supervision, Writing - review & editing.

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List of Acronyms

CAP	industrial fixed asset investment
CEI	comprehensive energy production rate
CO_2	total carbon dioxide emissions
DDF	directional distance function
DEA	the Data Envelopment Analysis decomposition method
DMU	decision-making unit
Demo	demonstration effect
EL	exploitation occupation and destruction of land area

EPI	environmental pollution index
EQI	environmental quality index
GML	global Malmquist-Luenberger index method
GHG	greenhouse gas
Industry	degree of coordination of industrialization
ISI	comprehensive utilization of solid industrial waste
ISWP	industrial solid wastes produced
ISWU	industrial solid waste utilization amount
KFA	investment in fixed assets in energy exploitation and selection industry
KRI	capital productivity
LAB	number of people engaged in energy extraction
LAI	labor productivity
Market	market's unified coordination degree
RCO	the compliance rate of chemical oxygen demand in wastewater
SCM	synthetic control method
SDE	the sulphur dioxide emissions compliance rate
SHL	the number of days above the second highest level of air pollution or more
TFP	total factor productivity
USC	utilization in previous years, storage capacity

Appendix

The Chinese government announced the energy extraction and enrichment areas in three batches, including the first batch of 12, the second batch of 32, and the third batch of 25. The provinces involved include Hebei, Shanxi, Inner Mongolia, Liaoning, and Jilin. Heilongjiang, Jiangsu, Anhui, Jiangxi, Shandong, Henan, Hubei, Hunan, Guangdong, Guangxi, Hainan, Chongqing, Sichuan, Guizhou, Yunnan, Shaanxi, Gansu and Ningxia. The specific area is shown in table A1.

Table A1
Descriptive statistics of energy resources exhausted areas

provinces	First published	Second published	Third published
Heibei		Xiahuayuan District(1), Yingshouyingzi District (1)	Jingxing Mining Area (1)
Shanxi		Xiaoyi City(1)	Huozhou City (1)
Inner Mongolia		Arxan(4)	Wuhai City(1), Shiguai District (1)
Liaoning	Fuxin City(1), Panjin City(2)	Fushun(1), Biepiao City(1), Gongchangling District(4), Yangjiazhangzi District(4), Nanpiao District (1)	
Jilin	Liaoyuan City(1), Baishan City(1)	Shulan City(4), Jiutai City(1), Dunhua City(4)	Erdaojiang District(1), WangQing (4)
Heilongjiang	Yichun City(4), Greater Khingan Range(4)	Qitaihe(1), Wudalianchi(4)	Hegang City(1), Shuangyashan City(1)
Jiangsu			Jiawang District(1)
Anhui		Huaibei(1), Tongling(1)	
Jiangxi	Pingxiang City(1)	Jingdezhen(4)	Xinyu City (4), Dayu(4)
Shandong		Zaozhuang(1)	Xintai(1), Zichuan District(1)
Heinan	Jiaozuo City(1)	Lingbao City(4)	Puyang(2)
Hubei	Dazhi City(4)	Huangshi City(1,4), Qianjiang City(2), Zhongxiang City(4)	Songzi(1)
Hunan		Zixin City(1), Lengshuijiang City(4), Leiyang (1)	Lianyuan City(1), Changning(4)
Guangdong			Shaoguan(1,4)
Guangxi		Heshan City(1)	Pinggui District(4)
Hainan			Changjiang(4)
Chongqing		Wansheng District(1)	Nanchuan District(1)
Sichuan		Huaying City(1)	Luzhou(3)
Guizhou		Wanshan District(4)	
Yunnan	Gejiu City(4)	Dongchaun District(4)	Yimen(4)
Shaanxi		Tongchuan City(1)	Tongguan(4)
Gansu	Baiyin City(4)	Yumen City(2)	Hongji District(1)
Ningxia	Shizuishan City(1)		
Total	12	32	25

Note: (1) represents coal, (2) represents oil, (3) represents natural gas, and (4) represents other non-energy resources.

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