Environmental Science and Pollution Research (2021) 28:60537–60549
https://doi.org/10.1007/s11356-021-14957-5

RESEARCH ARTICLE

Estimating the heterogeneous and dynamic economic impacts of China's energy consumption control policy

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Received: 10 September 2020 / Accepted: 13 June 2021 / Published online: 22 June 2021

Abstract

In the late stages of its industrialization, China's economy still largely relies on energy. With increasing pressures to protect the environment and reduce carbon emissions, in 2013, the Chinese government officially issued four policies in succession to control total energy consumption. In this paper, we use the single difference model to estimate the average and dynamic economic impacts of such policies. We also introduce the energy dependence degree and divide all industrial sectors into two categories to estimate heterogeneous and dynamic policy effects based on the difference-in-differences (DID) model. Our empirical study shows that the implementation of energy consumption control policies results in a decrease in economic growth rates. Meanwhile, the negative dynamic economic effects of such policies decrease levels of volatility. Furthermore, such policies have heterogeneous economic effects on levels of energy dependence across sectors and have more significantly negative economic impacts on heavily energy-dependent industries but with hysteresis. Heterogeneous and dynamic economic effects on heavily energy-dependent industries are decreasing. We conclude with recommendations on ways to mitigate the negative effects observed.

Keywords Energy consumption control policy · Dynamic economic influence · Heterogeneous economic impact · Single difference model · Difference-in-differences model

Introduction

Since the reform and opening-up, from 1979 to 2018, China's energy consumption, growing at an average annual rate of 5.4%, has supported an average annual economic growth rate of 9.4% according to The National Bureau of Statistics of China 2019. Energy has played an important role in ensuring national economic growth, promoting social progress and improving people's living standards. Energy is the "grain" of secondary industry, which has pivotal effect on ensuring the rapid development of the industrial sectors. Although China gradually enters the post-industrialization stage, the contribution of the secondary industry to economic growth still accounts for 40.7% in the year of 2018. Therefore, energy still plays a strong role in promoting the economic growth of China for a long time in the future.

Although energy consumption promotes economic development, excessive energy consumption causes environmental pollution problems (Zaman et al. 2016; Murat et al. 2016). In particular, energy structure dominated by fossil energy makes China became the largest CO_2 emitter in the world Qiang et al. (2018). Due to the serious pressure on carbon emission reduction, since 2013, China has put forward intensive requirements and targets for the implementation of total energy consumption control. The 12th 5-year plan for energy development, released on January 1, 2013, proposed the implementation of dual control of total energy consumption and intensity, and set a target constraint on total energy consumption in 2015. The action plan on prevention and control of air pollution, issued in September 2013, puts forward for the first time to control the total coal consumption. The energy development strategy action plan (2014~2020), released in November 2014, put forward that China's total primary energy consumption should be controlled in about 4.8 billion tons

Responsible Editor: Nicholas Apergis

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of standard coal in 2020. The 13th 5-year plan for energy development, released in December 2016, proposed that China's total energy consumption should be controlled within 5 billion tons of standard coal in 2020.

The implementation of total energy consumption control policies plays an important role in energy conservation and carbon emissions reduction. However, as energy is an important facet of economic growth, what are the average and dynamic impacts of total energy consumption control policies on economic growth? Different industries have varying levels of dependence on energy. Do energy consumption control policies have a more significant negative impact on the economic growth of heavily energy-dependent industries? To address these research questions, we apply the single difference model to estimate the average and dynamic economic impacts of energy control policies. We also apply the difference-in-differences (DID) model to estimate heterogeneous and dynamic policy effects. The research presented in this paper helps elucidate the effects of energy consumption control policies and can serve as a reference for the subsequent formulations and adjustments of relevant policies.

The remainder of this paper is organized as follows. The "Literature review" section summarizes the latest relevant research from China and abroad. The "Methodology" section describes the employed model's construction and data sources used. The "Empirical results" section presents our empirical results on the average and dynamic economic impacts of implementing total energy consumption control policies based on a single difference model and heterogeneous and dynamic economic impacts on heavily energy-intensive industries based on a difference-in-differences model. The "Robustness test" section tests the robustness of the empirical results. The "Conclusions and implications" section summarizes and provides policy recommendations.

Literature review

Energy consumption and economic growth

Before studying the impact of the implementation of total energy consumption control policy, it is necessary to clarify the relationship between energy consumption and economic growth. Kraft and Kraft (1978) first analyzed the data in the 27 years after the Second World War in the USA, and for the first time came to the conclusion that the relationship between energy consumption and economic development; that is, there is a unidirectional causal relationship between the two variables, and the increase in GDP leads to an increase in energy consumption.

Since then, many scholars have carried out research on this topic, and have formed relatively mature research results by analyzing data from regions, multinational organizations, and single countries. The existing research results can be roughly divided into two categories: co-integration relationship research and causality research. In terms of co-integration relationship research, most scholars believe that whether taking a group of countries (Kahouli 2017; Apergis and Payne 2009; Belke et al. 2010a, b; Streimikiene and Kasperowicz 2016) or a single country or region Li et al. (2011), there is a long-term linear cointegration relationship between energy consumption and economic growth, but sometimes with structural breaks (Gómez et al. 2018; Yavuz 2014), while some scholars have come to different conclusions that there is a non-linear cointegration relationship between energy consumption and economic growth (Pilatowska et al. 2015; Kourtzidis et al. 2018).

In terms of causality research, the relationship between energy consumption and economic growth mainly includes unidirectional causality and bidirectional causality. For unidirectional causality, some scholars have concluded that energy consumption promotes economic growth through empirical tests (Jalil and Feridun, 2014; Tao et al. 2020; Liu and Xue 2014; Chu and Chang 2012); at the same time, the impact of energy consumption has regional heterogeneity Li et al. (2011). Renewable energy consumption has a positive impact on economic growth (Bhattacharya et al. 2016; Shahbaz et al. 2018). Compared with coal and oil, consumption of natural gas and clean energy has a higher degree of impact on economic growth (Cheng and Liu 2019). Other scholars believe that economic growth brings an increase in energy consumption (Jing et al. 2011; Yi-Wen and Zong-Yi 2012; Komal and Abbas 2015). In countries with low economic growth rates, economic development has a relatively small impact on energy consumption growth, while in high-income countries, due to the increased awareness of energy conservation, the impact of economic development on energy consumption is still small (Shahbaz et al. 2015). In terms of bidirectional causality, some scholars believe that energy consumption and economic growth are mutually influential (Costantini and Martini 2010; Belke et al. 2010a, b); that is, energy consumption promotes economic development, and economic development increases energy consumption. In addition to the above research results, the conclusion of the relationship between energy consumption and economic growth separately from the long-term and short-term levels is explained by scholars. Apergis and Payne (2009) concluded that there is a unidirectional causality between energy consumption and economic development in the short term, while there is a bidirectional causality between the two variables in the long run. Jiang and Bai (2017) believed that there is a bidirectional causal relationship between China's energy consumption and economic growth in the short term, while economic growth in the long term leads to an increase in energy consumption. Hao et al. (2018) based on China's rural panel data and used the VECM and FMOLS models to conclude that there is a causality between rural economic development and energy consumption in the short term, and there is a unidirectional causal relationship between energy consumption and economic development in the long run.

Energy constraints and economic growth

In terms of the impact of energy constraints on economic growth, Hotelling proposed Hotelling Law 1931, introducing exhaustible energy into the economic growth model (1931). But before the 1960s, the economic growth of resource constraint problems has brought to the attention of the academia, and Hotelling' law was not be verified by the practice of major industrialized countries economic growth; therefore, until the outbreak of the world oil crisis in the 1970s, the resource constraints and energy constraints of economic growth entered the scope of economists' research, and the theory of energy economics began to spread widely. Stiglitz (1976) and Solow (1977) began to study the resource constraint of economic growth relatively early. Both economists believed that economic output could maintain long-term growth under the condition of a given stock of natural resources and expansion of population scale. When Rasche and Tatom (1977) studied the relationship between energy and economic growth, they were the first to introduce the energy factor into the Cobb-Douglas function, and they believed that in the path of balanced growth, the depletion of non-renewable energy would lead to unsustainable economic growth. James H et al. (2011) analyzed global data and studied the restrictive effect of energy on social and economic development with the method of macroecology, proving that energy constraint would reduce the growth of per capita GDP in the long run.

In recent years, a plenty of scholars have taken China as their research object and have conducted research this issue on the macro and micro levels, and have achieved relatively rich research results. At the macro level, Fanhua et al. (2013), Ying and Kun-rong (2010), and Li et al. (2014) established models to confirm that energy constraints can hinder the development of China's economy. Compared with coal, electricity constraints have a greater negative impact on economic growth (Xiao and Shu-Shan 2015). At the micro level, energy constraints have a restrictive effect on the development of enterprises and reduce their performance, but for low-energy companies, energy constraints will improve performance, and for high-energy companies, energy constraints will reduce corporate performance (Zhang et al. 2018). At the same time, there is regional heterogeneity in the impact of energy constraints on industrial enterprises. The reasonable implementation of energy policies can help increase the profitability of industrial enterprises and promote the development of enterprises Wang et al. (2018).

As a government means of energy constraint, the policy of total energy consumption control has also attracted the attention of Chinese scholars. Liu and Huachen (2015) took China's Beijing, Tianjin, and Hebei province as the research objects, built a dynamic panel model validation of China's total energy consumption control policy influence on industrial structure, and this study showed that the total energy consumption in the short-term control policy has a negative influence on the fundamentals of industrial structure; but with the change of technology and energy consumption structure, this policy can contribute to the advancement of China's industrial structure. Cui et al. (2016) used the GVAR model to conduct empirical analysis on provinces and cities in China, and concluded that the total energy consumption control has a stronger constraint in regions that are highly dependent on energy consumption than those that are weakly dependent. Jin (2012) analyzed the impact of China's total energy consumption control on the economy by using the multiplier model, and believed that the total energy consumption control had a direct or indirect negative impact on the output of the upstream and downstream sectors of the industry and hindered the development of economy.

In conclusion, existing studies have made it clear that energy consumption has an important impact on economic growth, and energy constraints will hinder economic growth. However, there is little quantitative research on the impact on economic development of restricting energy consumption. For the research object of this paper, the influence of the implementation of China's energy consumption control policy, although some scholars have studied it, but they focused on the analysis of the effect of policy on industrial economy and industrial structure, but not yet on the year-by-year dynamic economic impact of the total energy consumption control policy and the heterogeneous economic impact of industries with different energy dependence. Therefore, this paper takes China's total energy consumption control policy since 2013 as the research object, empirically estimating its dynamic and heterogeneous economic impacts. This study will supplement the existing literature in terms of research content and research perspective.

Methodology

Commonly used empirical methods for policy effect evaluation include propensity score matching (Jin 2012; Hu et al. 2012; Li 2010), the instrumental variable method (Sun and Chen 2017; Darren et al. 2017; Habibov et al. 2017; Du et al. 2015), regression discontinuity design (Zhang et al. 2014; Zou and Yu 2015; Liu et al. 2016), and difference-in-differences method (Jane, 2016; Jennifer and Tyler 2015; Nick and Katie 2015). Although the instrumental variable method can address endogenous and missing variables and identify the causal relationship between policy and dependent variables, it is difficult to select appropriate instrumental variables. The regression discontinuity design is not applicable to the present work because it cannot be used to take time as discontinuity. The propensity score matching method requires the existence of individuals affected by policies and of those not affected by policies and requires using a large amount of data, rendering it unsuitable for the present work. This paper examines the economic impacts of energy consumption control policies gradually strengthened since 2013 on industrial sectors. Since these policies have been implemented nationally and have affected all industries, we use the single difference method to study average and dynamic economic impacts on industrial sectors by introducing dummy variables to determine whether policies have been implemented, and we use other control variables to improve the model's accuracy. To study the heterogeneous and dynamic impacts of the studied policies on different industrial sectors, we divide sectors into two groups (treatment and control groups), and we use the difference-in-differences model to study the net impact of the studied policies on the treatment group.

Model construction

Average and dynamic economic impact model

The average economic impact model adopts the C-D production function as the model framework, which is shown in Eq. (1):

$$Y = A_0 e^{\lambda t} K^{\alpha} L^{\beta} \tag{1}$$

In Eq. (1), Y is the output, K is the capital investment, L is the labor input, A_0 is the constant and represents the degree of science and technology advancement of the base period, λ is the rate of technological progress, t is the time series, and α and β respectively represent the output elastic coefficients of capital and labor. For the purposes of this study, the model is transformed as follows:

Take the logarithm of both sides of Eq. (1) and then take the derivative with respect to time t to obtain:

$$\frac{1}{Y}\frac{dY}{dt} = \lambda + \frac{\alpha}{K}\frac{dK}{dt} + \frac{\beta}{L}\frac{dL}{dt} \tag{2}$$

Since the statistical data are discrete, the difference is used to substitute the differential, meaning that $dt = 1$. Thus:

$$\frac{\Delta Y}{Y} = \lambda + \alpha\frac{\Delta K}{K} + \beta\frac{\Delta L}{L} \tag{3}$$

Apply $y = \Delta Y/Y$, $k = \Delta K/K$, and $l = \Delta L/L$ to have:

$$y = \lambda + \alpha k + \beta l \tag{4}$$

In Eq. (4), y, k, and l respectively represent the average annual relative growth rates of output, capital, and labor.

To study the economic impact of the total energy consumption control policy gradually strengthened since 2013 on the output growth rate, the following panel data model is formed:

$$\begin{aligned} y_{it} = {} & c_i + \alpha_1 \times labor_{it} + \beta_1 \times invest_{it} + \eta_1 \times rd_{it} + \delta_1 \times fdi_{it} + \lambda_1 \times gm_{it} \\ & + \phi_1 \times d_t + \varepsilon_i \end{aligned} \tag{5}$$

In Eq. (5), i represents industry; t represents time; y, *labor*, and *invest* respectively represent the average annual growth rate of output, labor input, and capital input; *rd*, *fdi*, and *gm* respectively represent the average annual growth rate of science and technology input, foreign direct investment, and the industrial scale. Dummy variable d indicates whether the policy has been implemented. d is valued at 1 after the year 2013 and is valued at 0 in the other years.

To study the dynamic economic impact of the total energy consumption control policy on the growth rate of industrial output, the panel data model is further constructed as shown in Eq. (6):

$$\begin{aligned} y_{it} = {} & c_i + \alpha_2 \times labor_{it} + \beta_2 \times invest_{it} + \eta_2 \times rd_{it} + \delta_2 \times fdi_{it} + \lambda_2 \times gm_{it} + \\ & \phi_2 \times d2013_t + \phi_3 \times d2014_t + \phi_4 \times d2015_t + \phi_5 \times d2016_t + \varepsilon_{it} \end{aligned} \tag{6}$$

In Eq. (6), *d*2013, *d*2014, *d*2015, and *d*2016 represent dummy variables on whether policies were implemented in 2013, 2014, 2015, and 2016.

Heterogeneous and dynamic economic impact model

In previous studies, scholars classified industries based on levels of energy intensity. However, as the energy consumption scale of industrial sectors of high-energy intensity is not necessarily large, it is not reasonable to use energy intensity alone to reflect an industry's level of dependence on energy. Therefore, referring to the work of Liu and Zhao (2017), this paper introduces the concept of energy dependence to reflect the industrial sector's dependence on energy as a comprehensive indicator of energy intensity and energy consumption scale.

E_i represents the total energy consumption of industrial sector i and P_i represents the energy consumption scale and is expressed as follows:

$$P_i = \frac{E_i}{E_1 + E_2 + \ldots + E_n} \; (n = 1, 2, \ldots, 34) \tag{7}$$

e_i is the energy intensity of industrial sector i and is expressed as follows:

$$e_i = \frac{E_i}{GDP_i} \tag{8}$$

Data for the energy consumption scale and for the energy consumption intensity levels of each industrial sector are normalized as follows:

$$P_i' = \frac{P_i - \min P_i}{\max P_i - \min P_i} \tag{9}$$

$$e_i' = \frac{e_i - \min e_i}{\max e_i - \min e_i} \tag{10}$$

Then, we calculate the geometric average of energy intensity and energy consumption scale or $EI_i = \sqrt{P_i' \times e_i'}$ as the energy dependence of the ith industry. According to the above method, the energy dependence of each industry is calculated and divided according to the energy consumption levels of each industry in 2016. This paper divides 34 industrial industries into two categories, including heavily energy-dependent industrial sectors ($EI_i \geq 0.3$) and other industrial sectors ($EI_i < 0.3$). The results are shown in Table 9 in the Appendix.

To determine whether the total energy consumption control policy has had a more significant inhibiting impact on the growth rates of heavily energy-intensive sectors' outputs, taking heavily energy-intensive industrial sectors as a treatment group and the other industrial sectors as a control group, we build the difference-in-differences model illustrated by Eq. (11). Differences between the treatment and control groups observed before and after the policy's implementation are shown in Table 1.

$$y_{it} = \beta_0 + \beta_1 \cdot du + \beta_2 \cdot dt + \gamma \cdot du \times dt + \varepsilon_{it} \tag{11}$$

In Eq. (11), y_{it} is the output growth rate of sector i in year t, du is the sector dummy variable, and $du = 1$ and $du = 0$ respectively represent the treatment and control groups. dt is the time dummy variable, and $dt = 0$ and $dt = 1$ respectively represent the years immediately preceding and following the policy's implementation. ε is a random disturbance term. The coefficient γ of interaction term $du \times dt$ measures the policy's "net" influence on the treatment group.

In addition to being influence by the total energy consumption control policy, the growth rate of the industrial trade output is affected by other variables. To render our model more effective, other control variables are added to the basic model. The meanings of the control variables are consistent with those of Eqs. (5) and (6), which are not described here. The model is as follows:

$$\begin{aligned} y_{it} = {} & \beta_0 + \beta_1 \cdot du + \beta_2 \cdot dt + \gamma \cdot du \times dt + \beta_3 \cdot invest_{it} + \beta_4 \cdot labor_{it} + \beta_5 \cdot rd_{it} + \\ & \beta_6 \cdot fdi_{it} + \beta_7 \cdot gm_{it} + \varepsilon_{it} \end{aligned} \tag{12}$$

In Eq. (12), the coefficient γ of interaction term $du \times dt$ measures the policy's average influence on the treatment group. To determine the policy's dynamic effects in different years, we extend Eq. (12) with the following forms:

$$\begin{aligned} y_{it} = {} & \beta_0 + \gamma_1 \cdot du \times d2013 + \gamma_2 \cdot du \times d2014 + \gamma_3 \cdot du \times d2015 + \gamma_4 \cdot du \times d2016 + \\ & \beta_1 \cdot du + \beta_2 \cdot dt + \beta_3 \cdot invest_{it} + \beta_4 \cdot labor_{it} + \beta_5 \cdot rd_{it} + \beta_6 \cdot fdi_{it} + \beta_7 \cdot gm_{it} + \varepsilon_{it} \end{aligned} \tag{13}$$

In Eq. (13), γ_1, γ_2, γ_3, and γ_4 respectively represent the policy's "net" influence on the treatment group in 2013, 2014, 2015, and 2016.

Data

Since industrial gross output value data stopped being published in 2012, we replace these data with the industrial sector's gross sales using 2012 as the base period using data from China industrial economy statistical yearbook. Labor data are represented by the number of employees in industrial sectors at the end of a year based on data taken from the China labor statistical yearbook. Science and technology inputs are represented by R&D spending. The industry scale is calculated from "the output value of industrial enterprises from different sectors of above the designated size" divided by "the number of industrial enterprises from different sectors exceeding the designated size." Related data on science and technology inputs, foreign direct investment, and industry scales are taken come from the China industrial economy statistical yearbook. Our calculation of capital input levels of various industries adopts the "perpetual inventory method" while we calculate depreciation rates of various industries for 2001 to 2016 using the method outlined in Chen (2011).

Empirical results

Average and dynamic economic impacts

To avoid false regressions, a stationarity test of data must be carried out before regression estimation. Table 2 shows the unit root test results derived from the four test methods.

As can be observed from the above table, all variables are horizontally stable and can be directly estimated by regression.

Table 1 Differences between the treatment and control groups

	Before policy implementation	After policy implementation
Treatment group	$\beta_0+\beta_1$	$\beta_0+\beta_1+\beta_2+\gamma$
Control group	β_0	$\beta_0+\beta_2$

Table 2 Unit root test results

Variable	LLC	IPS	Fisher-ADF	Fisher-PP
y	−3.8956***	−1.8720***	89.9505***	158.0580***
invest	−10.2280***	−5.8302***	154.0240***	152.4140***
labor	−4.0844***	−4.8918***	131.8800***	232.8130***
e	−21.4268***	−7.0050***	139.1850***	271.4910***
rd	−15.2513***	−10.9991***	247.0930***	444.6930***
fdi	−12.8808***	−4.0128***	103.4250***	219.7020***
gm	−7.0408***	−4.6901***	123.1330***	227.2610***

Triple asterisks represent the significance level of 1%

Before estimating panel data, it is necessary to determine the setting form of the panel data model. The model setting test determines the following factors: whether the individual fixed effect model is better than the mixed regression model, whether the individual random effect model is better than the mixed regression model, whether the fixed effect model is better than the random effect model, and whether the time effect (i.e., the two-way fixed effect) must be considered in the fixed effect model. In this paper, Stata software is used for estimations, and model setting test results for the panel data are shown in Table 3.

As can be observed from the above table, from F test results of the individual fixed-effect model, the p-value is greater than 0.05, and thus the mixed regression model is accepted as a reasonable null hypothesis. LM test results for the individual random effect model show a p-value of greater than 0.05, and the mixed regression model is also accepted as a reasonable null hypothesis. Therefore, a mixed regression model should be established, and the estimation results of the model are shown in Table 4.

In Table 4, model 1 is the basic model with only dummy variables added. Other control variables are gradually added from model 2 to model 5. Model 6 divides the dummy variables into 4 years (2013, 2014, 2015, and 2016) to observe the dynamic impact of the policy. According to the estimation results of model 5, which includes all independent variables, the coefficient of the dummy variable is significantly negative. The implementation of the total energy consumption control policy has reduced the average growth rate of industrial output by 7.94%. Regarding its dynamic impact, the growth rate of total industrial output has respectively decreased by 10.31%, 5.77%, 8.42%, and 6.76% from 2013 to 2016.

Table 3 Model setting test results of panel data

Test object	Test statistic	p-value
Wald F test for FE	F (33,437) = 0.9100	0.6152
Breusch and Pagan LM test for RE	Chibar2 (01) = 0.0000	1.0000

Regarding other independent variables, labor and capital inputs play a positive role in driving industrial sector output growth. Investments in science and technology play a significant positive role in driving the total output of industrial sectors. The more investments are made in science and technology, the faster the total output of industrial sectors grows. Industry scale has a positive effect on the growth of total industry output, indicating that economic growth has a scale effect. Foreign direct investment has a negative impact on output growth from the estimation results of this model, but its estimation result is not significant. Foreign direct investment does not have a significantly positive effect on output growth, which may be the case because the panel data mixed regression model is constructed in this section, and heterogeneity between industries should make it impossible to produce consistent and significant estimation results for factors with little impact on output growth rates. In addition, the insignificantly negative effect of foreign investment variables observed is corroborated by the Lu (2008), who argued that foreign direct investment has a significantly negative spillover effect on the efficiency of state-owned enterprise production with differences observed between different types of enterprises.

Heterogeneous and dynamic economic impacts

Estimation results of heterogeneous economic impacts are shown in Table 5.

In Table 5, control variables, individual effects, and time effects are gradually added from model 1 to model 3 to estimate the average impact of the policy. According to the estimation results of the three models, coefficients of interaction term $du\times dt$ are significantly negative, reflecting the economic impact of the total energy consumption control policy on heterogeneous features, which indeed has a more significantly inhibitory effect on the growth of heavily energy-dependent industrial sectors' outputs. When all control variables are added to models, the estimation results show that the policy has reduced the output growth of heavily energy-dependent industrial sectors 7.56% more than it has for other industrial sectors.

Models 4~6 present estimation results for annual dynamic effects. The estimation results of model 6 show that the heterogeneous impact of the total energy consumption control policy on industrial sectors' output growth shows signs of hysteresis. The coefficient of cross term $d2013\times du$ is negative but not significant, showing that the effect of the total energy consumption control policy in 2013 on heavily energy-dependent industrial sectors shows no significant differences from effects observed in other industrial sectors. The coefficients of cross terms $d2014\times du$, $d2015\times du$, and $d2016\times du$ are

Table 4 Estimation results of average and dynamic economic impact models

Independent variables	Average impact				Dynamic impact	
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
constant	0.2089***	0.1467***	0.1441***	0.1455***	0.1407***	0.1389***
	(0.0075)	(0.0110)	(0.0109)	(0.0110)	(0.0113)	(0.0116)
invest		0.0872***	0.0775***	0.0767***	0.0791***	0.0800***
		(0.0161)	(0.0161)	(0.0161)	(0.0162)	(0.0163)
labor		0.5053***	0.4867***	0.4860***	0.4741***	0.5023***
		(0.0558)	(0.0555)	(0.0555)	(0.0559)	(0.0625)
rd			0.0256***	0.0254***	0.0250***	0.0249***
			(0.0073)	(0.0073)	(0.0072)	(0.0073)
fdi				−0.0008	−0.0008	−0.0007
				(0.0008)	(0.0008)	(0.0008)
gm					0.0219*	0.0243*
					(0.0134)	(0.0152)
d	−0.1162***	−0.0850***	−0.0857***	−0.0867***	−0.0794***	
	(0.0145)	(0.0141)	(0.0139)	(0.0140)	(0.0146)	
*d*2013						−0.1031***
						(0.0257)
*d*2014						−0.0577**
						(0.0240)
*d*2015						−0.0842***
						(0.0244)
*d*2016						−0.0676**
						(0.0288)
R2	0.1119	0.2709	0.2885	0.2899	0.2937	0.2966
Sample number	510	510	510	510	510	510

Triple, double, and single asterisks denote significance levels of 1%, 5%, and 10%, respectively. Values shown in brackets are the standard errors of the estimation coefficient

significantly negative, indicating that the implementation of the total energy consumption control policy reduced the output growth rate of heavily energy-dependent industrial sectors by 10.18%, 10.63%, and 4.82% from 2014–2016.

Robustness test

Robustness test of average and dynamic economic impact model

First, the placebo test is applied. Assuming that the implementation time of the total energy consumption control policy runs from 2010 to 2012, D'=1 when the year is 2010, 2011 or 2012 and D'=0 for the other years, the full sample dataset is used for re-estimation, and the results for model 1 are shown in Table 6. The estimation results of dummy variable D' with 2010, 2011, and 2012 used as policy implementation years are not significant. In addition, annual effects are estimated for 2010 to 2012, and the results are shown in model 2. The estimation coefficients of *D*2010, *D*2011, and *D*2012 are not significant, showing that an impact of adopting 2010, 2011, or 2012 as the policy implementation year does not exist, verifying that the policy's effect only appears in 2013 and thereafter.

Second, we change the time window to verify robustness. Sample data for 2006 to 2016 and for 2010 to 2016 are respectively used for re-estimation, and the results are shown in Table 7. According to estimation results of the model for the sample of 2006 to 2016, the estimation coefficient of dummy variable *d*, which represents policy implementation years running from 2013 to 2016, is significantly negative. The coefficient of dummy variable D', which represents policy implementation years running from 2010 to 2012, is positive and insignificant. The coefficient of *D*2010 is significantly positive and the coefficients of *D*2011 and *D*2012 are not significant. According to estimation results of the sample for 2010 to 2016, the estimation coefficient of *d* is still significantly negative, the estimation coefficient of D' is significantly

Table 5 Estimation results of average and dynamic heterogeneous economic impacts

Independent variable	Average impact			Dynamic impact		
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
du×*dt*	−0.0955***	−0.0794***	−0.0756**			
	(0.0266)	(0.0237)	(0.0248)			
*d*2013×*du*				−0.0305	−0.0807**	−0.0462
				(0.0351)	(0.0347)	(0.0434)
*d*2014×*du*				−0.0890**	−0.0758**	−0.1018***
				(0.0339)	(0.0307)	(0.0284)
*d*2015×*du*				−0.1469***	−0.1093**	−0.1063**
				(0.0426)	(0.0455)	(0.0421)
*d*2016×*du*				−0.1154***	−0.0511*	−0.0482*
				(0.0258)	(0.0313)	(0.0272)
du	0.0304	0.0456***	0.1038**	0.0187	0.0455	0.1038**
	(0.0197)	(0.0170)	(0.0409)	(0.0211)	(0.0170)	(0.0408)
dt	−0.0966***	−0.0629***	−0.0496	−0.0902***	−0.0623***	−0.0557**
	(0.0125)	(0.0150)	(0.0413)	(0.0136)	(0.0150)	(0.0418)
constant	0.2027***	0.1306***	0.1152***	0.2028***	0.1301**	0.1155**
	(0.0095)	(0.0129)	(0.0375)	(0.0095)	(0.0130)	(0.0377)
Control variables	No	Yes	Yes	No	Yes	Yes
Individual effect	No	No	Yes	No	No	Yes
Time effect	No	No	Yes	No	No	Yes
R2	0.1244	0.3063	0.4193	0.1286	0.3073	0.4207
Sample number	510	510	510	510	510	510

Triple, double, and single asterisks denote significance levels of 1%, 5%, and 10%, respectively. Values shown in brackets are the standard errors of the estimation coefficient

positive, the coefficients of *D*2010 and *D*2012 are significantly positive, and the estimation coefficient of *D*2011 is not significant. All of these results show that after changing the time window, the effect of policy implementation taking 2010~2012 as the test years still does not exist, and the policy's effect only appears in 2013 and thereafter, verifying the robustness of the empirical results given above.

Table 6 Results of the counterfactual test

Independent variables	Model 1	Model 2
D'	−0.0195 (0.0162)	
*D*2010		0.0367 (0.0240)
*D*2011		−0.1045 (0.0658)
*D*2012		−0.0075 (0.0241)
Control variables	Yes	Yes
R^2	0.2544	0.2823
Sample number	510	510

Triple, double, and single asterisks denote significance levels of 1%, 5%, and 10%, respectively. Values shown in brackets are the standard errors of the estimation coefficient

As another concern, other factors rather than the energy consumption control policy could have slowed economic growth after 2013. In fact, it is difficult to completely exclude this possibility. However, in constructing our economic impact model, we include other control variables that affect the economic growth of industrial sectors, which to some extent can exclude the competitive interpretation of empirical results by industry-level factors. In addition, since 2013, a major policy change that has affected the industrial sector involved the implementation of the total energy consumption control policy. Otherwise, it is difficult to find other factors that cause the empirical results to produce such a significant and consistent effect.

Robustness test of the heterogeneous and dynamic economic impact model

To test the robustness of the above empirical results, a placebo test is conducted. Assuming that 2010~2012 is the time period of policy implementation, the models are re-estimated as illustrated by model 1 in Table 8. We find that the cross-term coefficient is not significant, showing that the empirical findings only appear in 2013 and thereafter.

The difference-in-differences method is based on the premise that with no policy shocks, there is no systematic

Table 7 Test results derived from changing time windows

Independent variables	2006~2016			2010~2016		
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
d	−0.0601***			−0.0498**		
	(0.0158)			(0.0199)		
D'		0.0076			0.0475**	
		(0.0165)			(0.0198)	
$D2010$			0.0606**			0.1056***
			(0.0244)			(0.0266)
$D2011$			−0.0712			−0.0313
			(0.0757)			(0.0290)
$D2012$			0.0139			0.0472*
			(0.0238)			(0.0264)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
R2	0.3279	0.3018	0.3340	0.3348	0.3333	0.3777
Industry number	34	34	34	34	34	34
Sample number	374	374	374	238	238	238

Triple, double, and single asterisks denote significance levels of 1%, 5%, and 10%, respectively. Values shown in brackets are the standard errors of the estimation coefficient

difference in the output growth rate between the treatment and control groups. For this reason, we use the years 2010, 2011, and 2012, which precede the policy's application, as the years in which the event occurred and re-estimate. The results are illustrated by model 2 in Table 8. The cross term coefficients for these 3 years are not significant, showing that before the implementation of the total energy consumption control policy, there is no systematic difference in output growth rates between the control and treatment groups, meeting the precondition of difference-in-differences method. In fact, the present study is based on the difference-in-difference method's premise of studying the "net" influence of the total energy consumption control policy on the output growth of heavily energy-dependent industrial sectors, and thus it is not necessary to satisfy the cotrend hypothesis. Meanwhile, the estimation results of the three models also show that the policy effect does not exist for 2010, 2011, and 2012 and only during and after the year 2013.

Table 8 Robustness test results of the difference-in-differences model

Independent variables	Model 1	Model 2	Model 3
$du\times dt$	−0.0130 (0.0319)		−0.0589** (0.0277)
$d2010\times du$		0.0530 (0.0369)	
$d2011\times du$		−0.0920 (0.0677)	
$d2012\times du$		0.0977 (0.0646)	
dt	−0.0497 (0.0310)	−0.0524* (0.0287)	−0.3255* (0.2119)
du	0.0864 (0.0467)	0.0839 (0.0447)	−0.0237 (0.0632)
Control variables	Yes	Yes	Yes
Individual effect	Yes	Yes	Yes
Time effect	Yes	Yes	Yes
R2	0.4118	0.4116	0.4929
Sample number	510	510	238

Triple, double, and single asterisks denote significance levels of 1%, 5%, and 10%, respectively. Values shown in brackets are the standard errors of the estimation coefficient

We also change the time window of the sample to re-estimate. Applying the sample for 2010~2016 to estimate, the results are derived using model 3. The cross-term coefficient is still significantly negative at a significance level of 10%, verifying the robustness of the above results.

Conclusions and implications

This paper studies the impact of China's energy consumption control policy. Based on the single difference method, an average economic impact model is constructed, and the policy's impact on average and dynamic output growth in industrial sectors is empirically studied. Based on the difference-in-differences method, the heterogeneous and dynamic economic impact model is constructed and the policy's impact on the output growth of heavily energy-dependent industrial sectors is empirically studied. The following conclusions are drawn:

(1) China's energy consumption control policy has had a negative impact on the output growth of industrial sectors. As a result, the average growth rate of industrial sector output has decreased by 7.94% since 2013.

Regarding annual dynamic impacts, the total output growth rate of the industrial sector respectively decreased by 10.31%, 5.77%, 8.42%, and 6.76% from 2013 to 2016.

(2) The total energy consumption control policy has had a heterogeneous economic impact on different industrial sectors and has had a more significantly negative impact on the output growth rate of heavily energy-dependent industrial sectors. Compared to other industrial sectors, the output growth of heavily energy-dependent industrial sectors has fallen by 7.56% since 2013. In terms of annual dynamic impacts, the heterogeneous impact presents a certain lag, and the impact observed in 2013 is not significant while the output growth rate of heavily energy-dependent industrial sectors respectively decreased by 10.18%, 10.63%, and 4.82% from 2014 to 2016.

According to the empirical results, on one hand, the negative impact of the policy on the economic growth of industrial sectors shows a decreasing trend, reflecting the continuous improvement of the energy efficiency of industrial sectors under the pressure of the total energy consumption control policy. The policy is designed to help industrial enterprises continuously improve upon technical and energy efficiency levels to gradually reduce energy constraints on economic growth. On the other hand, the policy still has a negative impact on economic growth, and thus for the government, the energy consumption control policy adopted in China should be steadily promoted in consideration of future economic growth. In addition, energy consumption control can be further elaborated to industrial sectors and should be controlled based on the energy use patterns, energy saving capacities and energy saving potential of different industrial sectors to further optimize the policy and to promote the realization of total energy consumption control goals.

Appendix

Table 9 Energy dependence division in industrial sectors

Energy dependence division	Range	Industrial sectors	Energy consumption scale	Energy consumption intensity	Energy dependence
Heavily energy-dependent industrial sectors	$EI_i \geq 0.3$	Ferrous metal smelting and rolling	1	0.8550	0.9247
		Chemical raw materials and chemicals manufacturing	0.7655	0.5476	0.6475
		Petroleum product coking	0.3602	1.0000	0.6002
		Non-metallic mineral products	0.5377	0.4896	0.5131
		Thermal power production and supply	0.4064	0.4221	0.4142
		Nonferrous metal smelting and rolling	0.3214	0.5061	0.4033
		Coal mining and washing	0.1560	0.6971	0.3297
Other industrial sectors	$EI_i < 0.3$	Crude oil and natural gas	0.0634	0.6875	0.2087
		Textiles	0.1084	0.1459	0.1258
		Water production and supply	0.0166	0.8935	0.1219
		Paper and paper products	0.0596	0.2019	0.1097
		Non-metallic mining and other mineral processing	0.0277	0.4096	0.1065
		Rubber and plastic products	0.0657	0.1087	0.0845
		Metal products	0.0691	0.0918	0.0797
		Black metal mining	0.0224	0.2599	0.0764
		Agricultural and sideline food processing and food manufacturing	0.0907	0.0633	0.0758
		Chemical fiber manufacturing	0.0263	0.1735	0.0675
		Nonferrous metal mining	0.0148	0.3011	0.0667
		General equipment manufacturing	0.0517	0.0449	0.0482
		Pharmaceuticals	0.0317	0.0558	0.0420
		Wood processing and rattan, brown, and grass products	0.0172	0.0688	0.0344

Table 9 (continued)

Energy dependence division	Range	Industrial sectors	Energy consumption scale	Energy consumption intensity	Energy dependence
		Beverages	0.0196	0.0574	0.0335
		Gas production and supply	0.0072	0.1272	0.0302
		Transportation equipment manufacturing	0.0602	0.0146	0.0296
		Specialized equipment manufacturing	0.0253	0.0261	0.0257
		Electrical machinery and equipment manufacturing	0.0370	0.0133	0.0221
		Textile and clothing, shoe and hat manufacturing	0.0108	0.0188	0.0143
		Leather, fur, feathers (down), and associated products	0.0063	0.0228	0.0120
		Reproduction of printing and recording media	0.0037	0.0292	0.0104
		Furniture manufacturing	0.0023	0.0252	0.0076
		Culture, education, and sporting goods manufacturing	0.0026	0.0045	0.0034
		Instruments, instruments and culture, and office machinery manufacturing	0.0013	0.0062	0.0029
		Tobacco products	0	0.0033	0
		Communication, computer and other electronic equipment manufacturing	0.0457	0	0

Author contribution All authors contributed to the study conception and design. Material preparation, data collection, and analysis were performed by Qianqian Zhang and Rui-Ning Liu. The first draft of the manuscript was written by Qianqian Zhang and Rui-Ning Liu and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Funding This research is supported by the Basic Research Expenses for Municipal Universities in Beijing (Grant No. X21009).

Data availability The datasets used, generated, and analyzed during the current study are available in the China industrial economy statistical yearbook and Appendix in this paper.

Declarations

Ethics approval and consent to participate Not applicable.

Consent for publication Not applicable.

Competing interests The authors declare no competing interests.

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