



The impact of environmental regulation policy on firms' energy-saving behavior: A quasi-natural experiment based on China's low-carbon pilot city policy

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ARTICLE INFO

Keywords:

Command-and-control environmental regulation
Low-carbon city construction
Energy intensity
Enterprise heterogeneity

ABSTRACT

This paper explores the impact of environmental regulations on firms' energy-saving behavior by employing a quasi-natural experiment—China's low-carbon pilot (LCP) city policy. Using firm-level data and adopting a difference-in-differences (DID) model, we estimate the impact of China's LCP city policy on heterogeneous firms' energy conservation. The results show that the policy significantly reduces firms' coal consumption and coal intensity. In particular, energy-intensive industries and state-owned enterprises (SOEs) undertake larger energy conservation tasks. The effect on overall energy efficiency and the long-term effects are not as good. Our findings enrich existing research at the micro-level and have implications for authorities in China and other countries to propose environmental regulations.

1. Introduction

The problem of how to save energy has gained increasing attention worldwide. In 2018, according to the BP Statistical Yearbook of World Energy, China was the world's largest energy consumer, accounting for 24% of global energy consumption and 34% of global energy consumption growth. In recent years, the authorities in China have emphasized low carbon as part of the national strategy, and many environmental policies in China have been proposed to achieve this goal.

Environmental policies can be categorized into two kinds: command-and-control (CAC) environmental regulations and market-based policies. Market-based policies include pollutant discharge fees and tradable emissions, such as pollutant discharge fees and a carbon trading pilot reform. CAC regulations are mainly characterized by coerciveness, which depends on administrative measures (Xie et al., 2017), including setting emission reduction targets, forcing small energy- and emission-intensive enterprises to close, suspending enterprise

operations and so on.

Previous studies have different views on the effects of CAC environmental regulations on environmental performance. Li and Ramathanathan (2018) point out that CAC regulations have nonlinear relationships with the environmental performance of regions. Tang et al. (2018) prove that a pilot program decreases the land transfer of energy-intensive industries; however, the effect attenuates quickly over time. Tang et al. (2020a) prove that CAC environmental regulations hinder the growth in enterprise total factor productivity (TFP) because they increase costs and lower the efficiency of resource allocation. Similar findings have also been obtained by Li et al. (2019) and Tang et al. (2020b).

There are also studies that prove that both CAC policies and market-based instruments can have significant environmental benefits in developing countries; additionally, productivity effect driven by market-based regulations is much stronger than that driven by CAC policies (Xie et al., 2017). So, what will be the impact of CAC environmental regulations on firms' energy consumption and energy efficiency? Using a

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<https://doi.org/10.1016/j.resourpol.2021.102538>

Received 9 March 2021; Received in revised form 24 October 2021; Accepted 24 December 2021

Available online 13 January 2022

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quasi-natural experiment, China's low-carbon pilot (LCP) city policy, we try to answer this question.

As part of policy to reduce energy consumption, China proposed the construction of LCP cities, following London, Tokyo, and other cities. This paper aims to explore the effect of this policy on firms' energy-saving behavior. This policy was proposed by the National Development and Reform Commission (NDRC) in July 2010. It included five provinces and eight cities, most of which, such as Guangdong, Tianjin, Shenzhen, and Hangzhou, are relatively developed regions. It also included energy-intensive regions such as Liaoning, Shanxi, and Baoding. In April 2012, the LCP city project expanded to another 29 regions.

China's LCP city policy is largely driven by local governments, and a multi-layer and multi-actor policy-making process has been formed (Liu and Qin, 2016). The policy includes adjustment of the industrial structure, optimization of the energy structure, improvement in energy efficiency, and increase in carbon sinks (Khanna et al., 2014). The policy has no uniform rules in different regions, and among other things, the pilot regions develop their low-carbon development plans, establish low-carbon industrial systems, greenhouse gas emission data statistics and management systems, and greenhouse gas emission target responsibility systems; and provide support for low-carbon green lifestyles and consumption patterns (Tie et al., 2020).

The previous literature has proven that the policy had a considerable influence on the regions where the LCP city reform has been implemented. Notably, many regions have undergone significant changes in their industrial structure. For example, the share of industry in the GDP of the Great Khingan region decreased to 8.8% in 2014 from 23.7% in 2010, and the share of the service sector in the GDP of Qingdao increased to 52.8% from 46.8% (Li et al., 2018). The industrial structure undoubtedly has an effect on regional carbon emissions (Yu et al., 2018), and the LCP cities also adopt measures to change their industrial structure to achieve emission reduction targets, for instance, by reducing the land transfer of energy-intensive industries (Tang et al., 2018).

However, the practical energy-saving effects of environmental policies need to be carefully evaluated. Because of the pollution haven effect, although pollution charges can cause emission reduction, regional environmental regulations are also likely to cause pollution transfer from highly regulated regions to less regulated regions (Chung, 2014; Di, 2007). For instance, Wu et al. (2017) indicate that in China, highly polluting firms change their location from coastal provinces, which have strict environmental mandates, to western provinces, which have lax environmental mandates. Therefore, from the overall national perspective, the effect of regional environmental regulations was estimated too roughly. Compared with the effect on the industrial structure, the energy-saving effect within a sector has a more important meaning for the total energy-saving plan. Researches have been conducted on the effect of the LCP city policy on regional level (Chen et al., 2021; Cheng et al., 2019), but the within-sector change in energy intensity has not been measured.

Employing a unique data set containing details of firm-level energy consumption and firms' basis accounting, we use the difference-in-differences (DID) method to explore the change in within-sector energy efficiency in the LCP cities compared with other regions. That is, we focus on estimating the effect of the policy on firms' energy consumption and energy intensity.

We prove that the LCP city policy can significantly decrease firms' coal consumption and coal intensity, even when we control for the firm-level fixed effect, which is exactly the within-sector effect. Moreover, we find that the policy has a stronger effect on energy-intensive industries and a more significant effect on state-owned enterprises (SOEs). By using balanced panel data and the DID method based on propensity score matching (PSM-DID), we make a series of robustness tests, and prove that our main results are convincing. Our study makes three contributions.

First, the previous literature has not reached a unified conclusion about the impact of CAC policies on environmental performance. By

using a quasi-natural experiment—China's LCP policy, and employing a DID model, we answer the question of the impact of CAC environmental regulations on firms' energy consumption and energy efficiency. We find that CAC environmental regulations have a positive effect on firms' energy-saving behavior and energy efficiency.

Second, some previous studies have examined the effect of China's LCP city policy on energy consumption in pilot provinces and cities (Dai and Cao, 2015; Li et al., 2018). However, the estimated policy effect contains the change in the industrial structure and the within-sector energy efficiency, these studies cannot separate the change in within-sector energy efficiency. Using the firm-level fixed effect, we can explore the change in the energy efficiency of firms in the pilot cities, that is, the change in within-sector energy efficiency, and our study shows that there is an improvement in within-sector energy efficiency.

Third, we take advantage of the data to explore the heterogeneous effect of the CAC policy on firms. We do so because unlike market-based environmental regulations, CAC environmental regulations have no uniform rules and are mainly a kind of administrative order. Using a variety of heterogeneity tests, we identify that energy-intensive industries and SOEs undertake larger energy conservation tasks and focus on coal conservation. Our findings enrich existing research at the micro-level.

The rest of this paper is organized as follows: In section 2, we introduce the reform in detail and the related policy background. In section 3, we explain the econometric model and identification strategy as well as the data sources, discuss the data processing, and describe the data used for the dependent and independent variables. In section 4, we present the empirical results, including those of the benchmark regression, heterogeneity analysis, and robustness check. Finally, in section 5, we conclude the paper.

2. Low carbon pilot city policy

The world is facing increasing pressure to conserve energy and reduce emissions. Climate change has a profound impact on the survival and development of humankind and is a major challenge faced by all countries around the world. Responding to climate change is a major strategy for China's economic and social development, and it is also a major opportunity to accelerate the transformation of the economic development mode and economic restructuring. The low-carbon economy was first proposed by Kinzig and Kammen (1998) as a novel urban development mode. It provides a feasible idea for resolving the tensions between urban development, resource conservation, and environmental protection (Cheng et al., 2019).

China is now in a critical period of building a moderately prosperous society in all respects and of accelerating industrialization and urbanization. It is essential to explore the pathway to effectively control greenhouse gas emissions while developing the economy. According to the National Center for Climate Change Strategy and International Cooperation (NCSC), in response to China's 2020 action target for controlling greenhouse gas emissions set by the National Development and Reform Commission (NDRC), the LCP city policy was implemented.¹

The construction of low-carbon cities in China began on July 19, 2010, as seen in the *Circular on the pilot work of low-carbon provinces and cities* (2010, No. 1587). The first pilot regions included five provinces, namely, Guangdong, Liaoning, Hubei, Shaanxi, and Yunnan, and eight cities, namely, Tianjin, Chongqing, Shenzhen, Xiamen, Hangzhou, Nanchang, Guiyang, and Baoding. In 2012, the NDRC formulated the second group of pilot regions, as seen in the *Circular on launching the second batch of low-carbon pilot provinces and cities* (2012, No. 3760). The second pilot regions included Beijing, Shanghai, Hainan Province and Shijiazhuang, Qinhuangdao, Jincheng, Hulunbeier, Jilin, the Greater Hinggan Mountains region, Huaian, Zhenjiang, Suzhou, Ningbo,

¹ http://www.ncsc.org.cn/SY/dtsdysf/202003/t20200319_769716.shtml.

Wenzhou, Chizhou, and Nanping, in addition to Ganzhou city, Qingdao city, Jiuyuan city, Wuhan, Guangzhou, Guilin, Guangyuan, Zhunyi, Kunming, Yanan, Jinchang, and Urumqi. Notably, the construction of low-carbon cities has moved into its third stage, with approximately 36 pilot cities joining the program in 2017. Unfortunately, our data set does not cover 2017; therefore, our study covers only the pilot cities of the first two stages. Fig. 1 describes the pilot areas intuitively as follows:

The policy is mainly carried out by local governments, and it can be summarized in four points. First, the policy accelerates the establishment of low-carbon industrial systems in manufacturing, energy, construction, and transportation. It improves the industrial structure and energy structure and integrates the concept of low-carbon development into urban planning, including urban transportation planning and land use planning. It advocates buildings that conserve energy and adhere to low-carbon standards through using energy-efficient building materials, residential construction, and design.

Second, the policy establishes scientific carbon emission control targets based on local conditions. It assigns emission reduction tasks to administrative regions and key enterprises, and it tracks and evaluates the completion of the emission reduction tasks of these key enterprises.

Third, the policy establishes statistical and management systems for greenhouse gas emission data. It compiles a regional greenhouse gas emissions inventory, strengthens statistical work on greenhouse gas emissions, establishes a complete data collection and accounting system, and provides a basis for formulating regional greenhouse gas emission reduction policies.

Fourth, the policy advocates low-carbon and green lifestyles and consumption patterns, and it reduces the use of disposable goods. Additionally, it advocates public transport, such as cycling, walking and other low-carbon modes of travel, and it develops low-carbon transportation systems.

The LCP policy is a typical CAC environmental regulation. It mostly relies on the administrative orders of local governments and requires pilot areas to measure and determine their total greenhouse gas emission

control targets. The four points above cover all aspects of society, and the first, second and third points are closely related to our study.

Previous studies have proven that the effects of the LCP city policy include improving the green TFP of cities (Cheng et al., 2019), reducing the land transfer of energy-intensive industries (Tang et al., 2018), promoting policy innovation (Tie et al., 2020), and improving the distribution of urban logistics (Yang et al., 2016). Cheng et al. (2019) point out that LCP cities effect can be partly transformed into within-sector improvement and structural effects. The structural effects can be seen as the change in the proportion of energy-intensive industries, and there is no doubt that the LCP city policy will influence the industrial structure of regions. However, the question of how to observe the influence on the change in within-industry energy intensity remains unanswered by the existing literature. To answer this question, we use firm-level data and control for the firm fixed effect.

3. Econometric model and data

3.1. Econometric model

The standard model for estimating the impact of administrative energy-saving targets on energy efficiency involves regressing energy efficiency on administrative energy-saving targets using the ordinary least squares (OLS) method. However, direct OLS regression faces endogeneity problems caused by omitted variables, reverse causality and measurement error. That is, the relationship between administrative energy-saving targets and energy efficiency derived from direct OLS regression is not the real effect of policy on energy efficiency because the relationship is likely to be caused by omitted variables, reverse causality, or a variable measurement error. Therefore, we need to employ an exogenous shock as support to construct the causality between administrative energy-saving targets and energy efficiency.

Based on whether firms are affected by the reform, all firms are divided into two groups—the treatment and control groups—and the

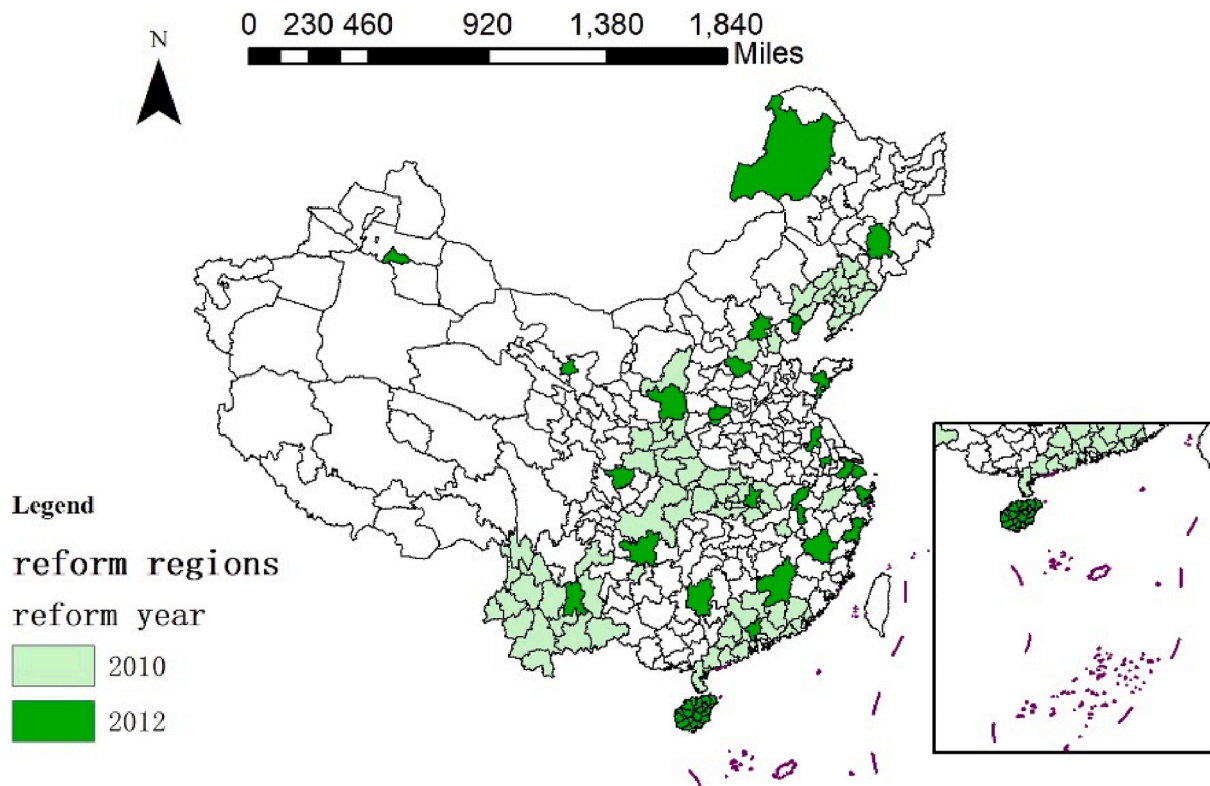


Fig. 1. Spatial distribution of two batches of low-carbon pilot areas in China.

reform results in a variation in China's LCP city policy for the treatment group but no variation in the policy for the control group in the post-reform period. The DID model estimates the difference in the change in energy efficiency between the treatment and control groups after the reform, and thus, it builds the causality between administrative energy-saving targets and energy efficiency. The control group provides a benchmark for the change in energy efficiency after the reform, and compared to the benchmark, the additional change in energy efficiency of the treatment group after the reform can be attributed to the effect of the policy.

DID models are widely used to identify policy effects (Bertrand et al., 2004; Dimick and Ryan, 2014; Lechner, 2011). The traditional DID model is a quasi-experimental method that uses longitudinal data collected from the treatment and control groups to generate appropriate counterfactual data that can then be used to estimate a causal effect. The traditional DID model considers two stages and two groups. Using the traditional DID model, the estimation model can be set as follows:

$$energy_{it} = \alpha_0 + \beta_1 time_{it} + \beta_2 treat_{it} + \beta_3 time_{it} \times treat_{it} + X_{it}\gamma + firm_i + year_t + \mu_{it},$$

where i denotes the firm, t denotes the year, and $energy_{it}$ is the energy consumption of firm i in year t . In the following analysis, we also study energy intensity, which is denoted as $energyint_{it}$. $time_{it}$ is the dummy variable for the year of the reform, and $treat_{it}$ is the dummy variable representing firms affected by the reform. X_{it} are the control variables used to control for different characteristics of firms, $firm_i$ represents the firm fixed effects, $year_t$ represents the year fixed effects, α_0 is the constant term, and μ_{it} is the error term.

China's LCP city reform was carried out in different areas over time. Thus, we use a specific DID model with multiple time periods to identify the policy effect.

Given that our data are pooled data with time and firm fixed effects, we set the model as follows:

$$energy_{it} = \alpha_0 + \beta after_{it} + X_{it}\gamma + firm_i + year_t + \mu_{it},$$

where $after_{it}$ is set to 1 if firm i implemented the LCP city policy in year t ; otherwise, this variable is set to 0. The other variables are the same as above.

There is one point that should be noted: We do not need the $time_{it}$ dummy and $treat_{it}$ dummy because we employ time fixed effects and firm fixed effects. The two dummies will be absorbed by the variables for the two types of fixed effects; thus, we do not need to control for the two dummies at all.

A detailed list of the control variables is provided as follows, and we explain why we chose them. Before doing so, we introduce the processing of the data set.

3.2. Data processing

The data set that we use consists of 2009–2013 energy consumption data from the National Tax Survey Database (NTSD). The data is firm-level data on firms with all types of ownership, of various sizes, and operating in various industries.

This data set has some advantages over the data sets in other studies. First, the observations in the sample cover all manufacturing industries and all regions, which constitutes a more representative sample to overcome the sample selection bias. Previous studies that examine firm-level energy efficiency cover only some industries and regions (Li, 2011) or focus only on large firms (Zhu et al., 2018). If the sample is limited to some regions or a part of manufacturing industries, it is hard to generalize the conclusions due to sample selection bias. Second, regarding the energy consumption data, other studies use data on total energy (Li, 2011) or energy consumption costs (Liao and Xu, 2019) from the World Bank dataset and the World Management Survey (Boyd and Curtis,

2014), which cannot separate different types of energy. We use a dataset including the coal, oil and electricity consumption of firms, so our study can investigate the effect of LCP reform on different kinds of energy intensity.

The data processing process is as follows: First, we eliminated some duplicate samples based on the taxpayer identification number and business name. Second, based on accounting standards, we eliminated some unreasonable samples: (1) firms which information on output is missing and firms with an output outside the range of (0.1, 99.9); (2) firms for which the year-end assets or fixed assets are negative or missing; and (3) organizational units categorized as S or T in the tertiary industry and firms whose industry codes are less than 5 digits. Moreover, based on the calculated energy intensity of enterprises within regions, we identified industries and regions with abnormal changes and eliminate outliers, and we also winsorized the top 0.1% and bottom 99.9% of the regression data.

In addition, the comparison of industry codes shows that the tax data implement GB/T 4754–2011 of the national economy industry classification in 2011. Based on this standard, we have unified industry codes. Different industries with different industry codes correspond to each other based on the industry name, and unified industry codes are generated. After the above treatment, 160,802 samples were included in this paper.

3.3. Data description

We control for the different characteristics of firms and their external environments because we control for firm effects. Additionally, the coefficients of the characteristics of some regions, for example, the energy prices of regions, are absorbed by this effect. We include the following variables in the regression model:

(1) Energy intensity (denoted by coal and energy)

Energy intensity is the dependent variable that we analyze. We mainly analyze coal intensity and explore the impact of the reform on firms' energy intensity. We focus on firms' coal intensity because coal consumption accounts for nearly 70% of the total primary fossil energy consumption in our study period² and most energy-intensive industries tend to rely on coal; moreover, a coal cap is more costly than a cap on all fossil fuels (Karplus et al., 2016). Therefore, we mainly analyze the effect of the policy on coal intensity. In addition, we convert coal, oil, and electricity consumption into coal equivalent using the standard heat values and, in a robustness check, analyze the effect on standard coal intensity, which is denoted by energy. Energy intensity is calculated by the following formula:

$$energy\ intensity = \frac{energy\ consumption}{output}$$

(2) Cities' GDP per capita (denoted by gdpper)

Cities' GDP per capita is used to measure the level of economic development. In general, developed areas have better external environments for efficient production, and firms in more developed areas will be subjected to agglomeration effects (Markandya et al., 2006; Yu, 2012). Moreover, considering that provincial GDP per capita varies little across all firms and county-level data are not as good, we use city-level GDP per capita.

We speculate that cities' GDP per capita has a negative relationship with energy intensity.

² The data are from the website of the National Bureau of Statistics: <https://data.stats.gov.cn/easyquery.htm?cn=C01>.

(3) Firm scale (denoted by assets)

In energy-intensive industries, there exist scale economics, which has been proven in many previous studies (Cole et al., 2005; Fisher-Vanden et al., 2015; Hassan and Romilly, 2018). Hassan and Romilly (2018) prove that as enterprises increase in scale, they can more easily obtain financial credit; thus, they invest in energy-saving innovations for production to improve their energy efficiency.

Therefore, we suggest that the impact of firm scale on energy intensity is negative, and we use firms' fixed assets to measure this index.

(4) Capital-to-labor ratio of the firm (denoted by klratio)

The capital-to-labor ratio reflects physical capital intensity. Previous studies have shown that physical capital-intensive firms are usually energy-intensive firms (Cole et al., 2006; Lan et al., 2012).

We predict that the capital-to-labor ratio has a positive relationship with energy intensity, and we use fixed assets divided by wages to measure this index.

(5) Return on assets of the firm (denoted by roa)

It is uncertain whether the energy intensity of firms with a high return on assets (ROA) is either higher or lower. Firms with a higher ROA usually have a greater productive ability; thus, they may have a lower energy intensity. Sometimes, firms exchange a higher energy consumption for a higher short-run ROA.

Therefore, we cannot predict the relationship between ROA and energy intensity. We use profits divided by the owner's equity to measure this index.

The summary statistics of all the variables are shown below in Table 1:

4. Results

4.1. Benchmark results

In the benchmark regression, we test the effect of the reform on firms' coal consumption and coal intensity. We start the estimation by controlling for firm fixed effects and year fixed effects in column (1) of Table 2 and find that the coefficient is significantly negative. This result means that the reform reduces firms' coal consumption and coal intensity. In column (2), we add additional control variables. In columns (3) and (4), we test the impact on firms' coal intensity; in column (3), we control for only the fixed effect, whereas in column (4), we control both for the fixed effect and the control variables.

The detailed results are as follows: (1) Column (2) indicates a semi-elasticity of coal consumption with respect to the LCP city policy of -0.2818 . This result means that after the reform, firms' average coal consumption decreases by almost 28%; similarly, their average coal intensity decreases by almost 24%, which is a significant energy-saving effect. (2) There exists an economic return of firms' coal intensity along with their size, and our results show that larger firms exhibit better energy efficiency, which is consistent with Karplus et al. (2018). (3) Firms' capital-to-labor ratio has a positive relationship with their coal intensity, which is similar to the findings of Cole et al. (2006). (4) Firms' ROA has a significant negative relationship with their coal intensity, which means that firms with higher profitability will have a lower coal intensity.

4.2. Heterogeneous effect analysis

To test the different effects of the LCP city project on different kinds of firms, we introduce cross-sectional variation to analyze the effect on firms in different industries and with different types of ownership, in addition to the effect on different kinds of energy.

First, we address the question of whether the reform has different effects on energy-intensive industries and other industries. Based on the NDRC, we define six two-digit industries as energy-intensive industries.³ By dividing the full sample into energy-intensive industry samples and the other industry samples, we conduct heterogeneity analysis. Table 3 below shows the detailed results:

From the results shown in Table 3, it is obvious that the coefficient of the policy effect on coal consumption of the energy-intensive industry subsample is lower than that of the other subsample. This result means that firms in energy-intensive industries will show greater decreases in coal consumption. The coefficient of the policy effect on coal intensity are similar. In other words, the LCP city reform has a larger influence on energy-intensive industries, the enterprises in energy-intensive industries show a greater decrease in coal consumption. When the policy reaches different regions, to achieve energy-saving targets, the government always assigns energy-saving tasks to energy-intensive industries and sets stricter energy conservation and emission reduction standards for these firms.

Second, we analyze the impact on firms with different types of ownership. We also conduct subsample regressions, and set the ownership dummy as follows: State-owned firms are denoted as *SOEs*, privately owned firms are denoted as *Private*, and Hong Kong, Macao, Taiwan and foreign-owned firms are denoted as *Foreign*. The results are shown in Table 4.

From the regression results, the coefficients of the policy effect on coal consumption and coal intensity of the state-owned subsamples are much lower than those of the subsamples with other types of ownership. This result means that the policy effect is much stronger on SOEs than on other types of enterprises, and this finding is similar to that obtained by Qi et al. (2021).

The LCP city policy is a typical CAC environmental regulation. There are no specific rules about carbon emissions, and the policy mostly relies on the administrative orders of local governments. Traditionally, SOEs are perceived as initiating and engaging in corporate social responsibility activities (See, 2009), such as employment creation (Carroll, 1979; Kemp, 2001) and environmental protection (Moon and Shen, 2010; See, 2009; Wang and Qian, 2011). Cheng et al. (2017) find that political connections can significantly increase the level of corporate environmental information disclosure, especially in highly polluting industries. Therefore, we can conclude that CAC environmental policies have a stronger effect on SOEs.

Third, we test the effect of the policy on different kinds of energy, and the results are shown in Table 5. Compared with the heterogeneity analysis above, we only replace the independent variables with electricity consumption (column (1)), electricity intensity (column (2)), oil consumption (column (3)), and oil intensity (column (4)). Moreover, we convert coal, oil, and electricity consumption into coal equivalent using the standard heat values, shown as energy; in the regression, they are shown in column (5) (energy consumption) and column (6) (energy intensity).

From the results, we find that only electricity consumption and total energy consumption show a significant decrease; there is no significant effect on energy intensity. Under administrative orders, enterprises reduce their energy consumption based on the carbon emission reduction target. Compared with coal and electricity, equipment that uses oil has less consumption flexibility, Chen et al. (2021) points out that some regions reduce the consumption of coal and increase the use of petroleum and natural gas under the pressure of a low-carbon economy.

³ The energy-intensive industries include petroleum, coal and other fuel processing industries; chemical raw materials and chemical products manufacturing; the manufacture of nonmetallic mineral products; ferrous metal smelting and rolling processing; nonferrous metal smelting and rolling processing; and electric power and heat production and supply. The two-digit industry numbers are C25, C26, C30, C31, C32, and D44, respectively.

Table 1
The descriptions of the variables.

variable			mean	sd	min	p25	p50	p75	max	N
coal consumption	<i>lncoal</i>	firm-level	5.035	3.272	0	2.485	4.875	7.223	15.48	160802
coal intensity	<i>lncoalint</i>		−5.265	2.730	−14.17	−7.046	−5.132	−3.444	3.393	160802
GDP per capital	<i>lngdpper</i>	city-level	10.65	0.707	8.712	10.11	10.60	11.23	12.89	160802
asset	<i>lnasset</i>	firm-level	10.37	1.937	5.453	9.004	10.25	11.61	17.14	160802
capital-labor ratio	<i>klratio</i>		7.315	13.77	0.0418	1.208	2.974	6.980	96.76	160802
return on assets	<i>roa</i>		0.0540	0.097	0.00003	0.00800	0.0243	0.062	1.433	160802

Table 2
The impact of reform on firms' coal consumption and coal intensity.

VARIABLES	(1)	(2)	(3)	(4)
	<i>lncoal</i>	<i>lncoal</i>	<i>lncoalint</i>	<i>lncoalint</i>
<i>after</i>	−0.2949** (0.117)	−0.2818** (0.116)	−0.2247** (0.088)	−0.2357*** (0.086)
<i>lngdpper</i>		−0.1997 (0.313)		0.1834 (0.275)
<i>lnasset</i>		0.2875*** (0.023)		−0.2367*** (0.028)
<i>klratio</i>		−0.0052*** (0.001)		0.0029*** (0.0001)
<i>roa</i>		0.4675*** (0.097)		−0.7228*** (0.087)
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	136,597	136,597	136,597	136,597
R-squared	0.899	0.899	0.823	0.824

Robust standard errors in parentheses; ***p < 0.01, **p < 0.05, *p < 0.1.

Table 3
Heterogeneous effect analysis of different energy intensity industries.

VARIABLES	(energy-intensive industries)	(the other industries)	(energy-intensive industries)	(the other industries)
	<i>lncoal</i>	<i>lncoal</i>	<i>lncoalint</i>	<i>lncoalint</i>
<i>after</i>	−0.3377*** (0.116)	−0.2549** (0.123)	−0.2395** (0.097)	−0.2316*** (0.087)
<i>lngdpper</i>	−0.2827 (0.341)	−0.1961 (0.343)	0.2094 (0.302)	0.1301 (0.322)
<i>lnasset</i>	0.3432*** (0.034)	0.2650*** (0.031)	−0.1642*** (0.044)	−0.2667*** (0.032)
<i>klratio</i>	−0.0050*** (0.001)	−0.0054*** (0.001)	0.0004 (0.001)	0.0011 (0.001)
<i>roa</i>	0.8154*** (0.146)	0.3363*** (0.108)	−0.3373** (0.157)	−0.8699*** (0.105)
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	42,367	94,004	42,367	94,004
R-squared	0.904	0.881	0.827	0.804

Robust standard errors in parentheses; ***p < 0.01, **p < 0.05, *p < 0.1.

Notably, overall, the LCP city policy reduces energy consumption by approximately 14%, but the CAC environmental regulation cannot improve energy efficiency for a long time, which is similar to the findings obtained by Tang et al. (2018).

4.3. Parallel trend test and dynamic effect analysis

The validity of our main results shown in Table 2 relies on the assumption that there are no differences in the trends of the treated firms and control firms in the pretreatment period (Beck et al., 2010; Nunn and Qian, 2011). In other words, the difference between the treatment and control groups should be constant over time; if the two groups had significant differences before the policy, our results could be caused by the time trend instead of the LCP city policy. We next examine the parallel trend of the policy and examine the dynamic effect at the same

time. We do so by including a series of dummy variables in the standard regression to capture the year-by-year effects, which is similar to Beck et al. (2010). The model is as follows:

$$energy_{it} = \alpha_i + \beta_{-2}D_{it}^{-2} + \beta_{-1}D_{it}^{-1} + \beta_1D_{it}^1 + \beta_2D_{it}^2 + \beta_3D_{it}^3 + firm_i + X_{it}\gamma + year_t + \mu_{it}$$

where D_{it}^{-j} indicates the j-th year prior to the reform and D_{it}^j indicates the j-th year after the reform; for example, D_{it}^{-2} indicates two years earlier or prior to the reform and D_{it}^3 indicates three years after the reform. We exclude reform year D_{it}^{-1} to avoid multicollinearity problems. The results are shown below in Table 6.

Table 6 lists the results for both coal consumption and coal intensity. It illustrates two key points: Coal consumption and coal intensity were not different between the treatment group and the control group before policy⁴; the coal intensity and coal consumption of the treatment group decreased significantly after the policy. As shown, the coefficients on the policy dummy variables are not significantly different from zero for all years before the policy. These results mean that there are no differences in the trends of the treated firms and control firms in the pretreatment period (Beck et al., 2010; Nunn and Qian, 2011) and that the existence of the common trends between the treatment group and control group is the key to our identification (Agovino et al., 2016). Next, after the policy, we find statistically significant reductions in both coal consumption and coal intensity, which means that firms' coal consumption and coal intensity fall immediately. However, the policy effect weakens over time, which means that the CAC environmental regulation has only a short-term effect on firms' energy-saving behavior.

4.4. Triple differences analysis results

Another concern is that the LCP pilot policy may be targeted at different enterprises; thus, some enterprises may not fall under the scope of the policy. We use the triple difference (DDD) method to solve this problem. Because the LCP city policy did not regulate specific industries, local governments mostly focus on energy-intensive industries. As discussed above, the basic DID estimator may be biased if local governments place different levels of pressure on different industries to reduce emissions. Therefore, by adding an enterprise dummy for energy-intensive industries and taking the "industry" as the third difference dimension, we estimate DDD regressions as an additional test. Referring to Moser and Voena (2012) and Athey and Imbens (2022), the regression

⁴ Our data set could meet the parallel trend assumption. That is, although there are differences in the industrial structure among different regions, these differences influence the policy effect only in the regional analysis and do not influence the policy effect in the firm-level analysis. The reason is that the NTSD contains samples of all industries, collected by the State Administration of Taxation of China and the Ministry of Finance of China (SAT-MOF) based on the stratified random sampling method. Thus, from the firm-level perspective, the distribution of firms belonging to different industries in different regions is random and obey normal distribution. We also control for the firm fixed effect to control for the unobserved invariable influence factor of firms, which makes it possible to identify the within-sector policy effect and to exclude the influence of the industries.

Table 4
Heterogeneous effect analysis of different ownership firms.

VARIABLES	(SOEs)	(Private)	(Foreign)	(SOEs)	(Private)	(Foreign)
	<i>lncoal</i>	<i>lncoal</i>	<i>lncoal</i>	<i>lncoalint</i>	<i>lncoalint</i>	<i>lncoalint</i>
<i>after</i>	−0.4177*** (0.157)	−0.2454** (0.122)	−0.3019*** (0.111)	−0.4079*** (0.135)	−0.1968** (0.080)	−0.2881*** (0.108)
<i>lngdpper</i>	0.2107 (0.514)	−0.2658 (0.341)	−0.1520 (0.383)	0.2923 (0.542)	0.2181 (0.308)	0.0478 (0.416)
<i>lnasset</i>	0.2439*** (0.082)	0.2685*** (0.024)	0.3780*** (0.061)	−0.1696** (0.079)	−0.2657*** (0.030)	−0.2218*** (0.065)
<i>klratio</i>	−0.0022 (0.004)	−0.0052*** (0.001)	−0.0061*** (0.002)	0.0038 (0.003)	0.0013 (0.001)	−0.0018 (0.002)
<i>roa</i>	0.4585 (0.303)	0.4661*** (0.116)	0.4214** (0.186)	−0.2331 (0.351)	−0.8448*** (0.101)	−0.7997*** (0.199)
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	9464	97,571	19,959	9464	97,571	19,959
R-squared	0.887	0.895	0.910	0.812	0.821	0.843

Robust standard errors in parentheses; ***p < 0.01, **p < 0.05, *p < 0.1.

Table 5
Heterogeneous effect analysis of different kinds of energy.

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
	<i>lnelec</i>	<i>lnelecint</i>	<i>lnoil</i>	<i>lnoilint</i>	<i>lnenergy</i>	<i>lnenergyint</i>
<i>after</i>	−0.1913* (0.101)	−0.1420 (0.111)	−0.0464 (0.165)	−0.0123 (0.162)	−0.1401* (0.080)	−0.0952 (0.076)
<i>lngdpper</i>	0.2494 (0.424)	0.6530 (0.422)	0.7769 (0.554)	0.9887* (0.555)	0.0831 (0.259)	0.4627* (0.263)
<i>lnasset</i>	0.2788*** (0.020)	−0.2444*** (0.034)	0.2340*** (0.025)	−0.2553*** (0.033)	0.3142*** (0.019)	−0.2098*** (0.032)
<i>klratio</i>	−0.0041*** (0.001)	0.0018** (0.001)	−0.0035*** (0.001)	0.0021** (0.001)	−0.0049*** (0.001)	0.0011* (0.001)
<i>roa</i>	0.4791*** (0.098)	−0.7107*** (0.115)	0.4171*** (0.085)	−0.7125*** (0.103)	0.5590*** (0.072)	−0.6273*** (0.088)
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	133,146	133,146	109,820	109,820	160802	160802
R-squared	0.797	0.622	0.743	0.641	0.886	0.738

Robust standard errors in parentheses; ***p < 0.01, **p < 0.05, *p < 0.1.

Table 6
The dynamic impact of policy on the firms' energy saving.

VARIABLES	(1)	(2)
	<i>lncoal</i>	<i>lncoalint</i>
<i>before_3</i>	0.0125 (0.031)	0.0403 (0.036)
<i>before_2</i>	−0.0142 (0.031)	−0.0024 (0.035)
<i>current</i>	−0.2366*** (0.022)	−0.1845*** (0.025)
<i>post_1</i>	−0.4333*** (0.030)	−0.3501*** (0.032)
<i>post_2</i>	−0.2314*** (0.031)	−0.1904*** (0.033)
<i>post_3</i>	−0.1022*** (0.036)	0.0243 (0.039)
Control variables	Yes	Yes
Firm FE	Yes	Yes
Year FE	Yes	Yes
R-squared	0.010	0.020
Observations	162,188	160,802

Robust standard errors in parentheses; ***p < 0.01, **p < 0.05, *p < 0.1.

model is as follows:

$$\begin{aligned}
 energy_{it} = & \alpha_0 + \beta_1 time_{it} + \beta_2 treat_{it} + \beta_3 time_{it} \times treat_{it} + \beta_4 intind_{it} \\
 & + \beta_5 intind_{it} \times time_{it} + \beta_6 intind_{it} \times treat_{it} + \beta_7 time_{it} \times treat_{it} \times intind_{it} \\
 & + X_{it}\gamma + firm_i + year_t + \mu_{it}
 \end{aligned}$$

where *intind_{it}* is the enterprise dummy of energy-intensive industries. We define as 1 if the enterprise belongs to an energy-intensive industry and 0 otherwise. Based on the NRDC, the energy-intensive industries include petroleum, coal and other fuel processing industries; chemical raw materials and chemical products manufacturing; the manufacture of nonmetallic mineral products; ferrous metal smelting and rolling processing; nonferrous metal smelting and rolling processing; and electric power and heat production and supply.⁵ Furthermore, because we control for the firm fixed effect and year fixed effect, the relative coefficients of the year or firm or the industry dummy are omitted. The results are as follows in Table 7:

The DDD estimator β_7 measures the additional effect of the LCP city policy on energy-intensive industries. The results confirm that the LCP city policy significantly reduces coal consumption and coal intensity. In the treated subclass, the coal consumption of enterprises in energy-intensive industries additionally decreased by approximately 24% after the policy (significant at the 1% level); similarly, their coal in-

⁵ The two-digit industry numbers of these industries are C25, C26, C30, C31, C32, D44, respectively.

Table 7
Triple difference analysis results.

VARIABLES	(1)	(2)	(3)	(4)
	<i>lncoal</i>	<i>lncoal</i>	<i>lncoalint</i>	<i>lncoalint</i>
$time_{it} \times treat_{it} \times intind_{it}$	−0.2535*** (0.091)	−0.2429*** (0.090)	−0.1700** (0.083)	−0.1831** (0.082)
Control variables	No	Yes	No	Yes
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	136,597	136,597	136,597	136,597
R-squared	0.899	0.899	0.823	0.824

Robust standard errors in parentheses; ***p < 0.01, **p < 0.05, *p < 0.1.

Table 8
Robustness test in the balanced sample.

VARIABLES	(1)	(2)	(3)	(4)
	<i>lncoal</i>	<i>lncoal</i>	<i>lncoalint</i>	<i>lncoalint</i>
<i>after</i>	−0.1544** (0.065)	−0.1507** (0.065)	−0.1673*** (0.058)	−0.1741*** (0.057)
Control variables	No	Yes	No	Yes
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	16,695	16,695	16,695	16,695
R-squared	0.899	0.900	0.800	0.801

Robust standard errors in parentheses; ***p < 0.01, **p < 0.05, *p < 0.1.

tensity additionally decreased by approximately 18% (significant at the 1% level). The results prove that our main results are still significant.

4.5. Other robustness analysis

To further test the robustness of the basic results, we conduct a sensitivity analysis along four dimensions: using balanced observations, using the PSM-DID method, controlling for other related policies, and controlling for the time trend.

In the first dimension, we retain the samples that appear in all years. We do so because large differences in the observations in different years will influence the average treatment effect to some extent; thus, in this section, we retain only the firms that appear in all years to solve this problem.

The results are shown in Table 8, and the independent variables are the logarithms of firms' coal consumption and coal intensity. From the results, we find that the coefficient of the policy effect is still significantly negative and similar to the benchmark results. This result means that the LCP city reform can reduce firms' coal consumption and coal intensity.

In the second dimension, we mainly use the PSM-DID method to test the robustness of the results. First, we use a logit model with the experimental group dummy variable as the dependent variable, firms' control variables as the covariates, and firms' coal consumption as the independent variable. Then, we use the nuclear matching method to match the samples. After matching, we drop the observations that are not matched and then obtain the balance check of the distribution of the covariates between the experimental group and the control group.

Table 9 shows that after matching, the experimental group and the control group have little difference; in other words, the difference is approximately 0. The *t*-test proves that the null hypothesis of no systematic bias in the treatment and control groups is not rejected. The matching result is effective, and the model can be estimated by the PSM-DID method.

Then, we use the sample to estimate the DID model and obtain the results shown in Table 10, from which it is obvious that the policy effect is significant. The coefficient of the policy effect is significantly negative and, compared with the benchmark results, is just slightly higher. Specifically, the policy can reduce firms' coal consumption by 29% and

Table 9
The PSM validity test.

variable	Experimental group mean	Control group mean	difference	T value	P value
<i>lnasset</i>	10.360	10.397	−0.037	−3.665	0.999
<i>klratio</i>	7.273	7.340	0.067	0.939	0.808
<i>roa</i>	0.059	0.051	−0.009	−16.290	0.487

Table 10
Robustness test — PSM-DID results.

VARIABLES	(1)	(2)	(3)	(4)
	<i>lncoal</i>	<i>lncoal</i>	<i>lncoalint</i>	<i>lncoalint</i>
<i>after</i>	−0.3043*** (0.114)	−0.2923** (0.114)	−0.2423*** (0.093)	−0.2504*** (0.091)
Control variables	No	Yes	No	Yes
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	89,494	89,494	89,494	89,494
R-squared	0.903	0.903	0.829	0.829

Robust standard errors in parentheses; ***p < 0.01, **p < 0.05, *p < 0.1.

reduce their coal intensity by 25%.

In the third dimension, we consider the other related policy: the carbon trading pilot reform (denoted as *ctp*). China implemented its carbon emissions trading system in seven pilot cities⁶ in 2011; in these cities, carbon emissions can be traded, and firms with low energy efficiency have to pay a cost. This reform is an instrument that the government uses to reduce total carbon emissions. The literature has proven that this policy will decrease the total carbon emissions of regions (Ding et al., 2019; Wang et al., 2019); thus, we should exclude the effect of this policy to ensure the credibility of our conclusion.

In Table 11, we control for the carbon trading pilot reform (denoted by *ctp*). The results show that the LCP cities are still significantly negative, not only regarding firms' coal consumption but also regarding firms' coal intensity. Additionally, the coefficients are similar to those of the benchmark regression, proving that our results are robust.

Finally, considering that the response of different regions to coal prices and other unobserved factors is different, the difference trend between the treatment group and control group may cause the results to be biased, and the coal prices in different regions may have different influences on the results. To solve these problems, first, following Angrist and Pischke (2008), we control for the time trend, and the results are shown in columns (1) and (2) of Table 12. Second, we control for coal prices to control for the impact caused by the variation in coal

Table 11
Robustness test — Control other policy.

VARIABLES	(1)	(2)	(3)	(4)
	<i>lncoal</i>	<i>lncoal</i>	<i>lncoalint</i>	<i>lncoalint</i>
<i>after</i>	−0.2906** (0.116)	−0.2755** (0.115)	−0.2219** (0.087)	−0.2316*** (0.085)
<i>ctp</i>	Yes	Yes	Yes	Yes
Control variables	No	Yes	No	Yes
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	136,597	136,597	136,597	136,597
R-squared	0.899	0.899	0.823	0.824

Robust standard errors in parentheses; ***p < 0.01, **p < 0.05, *p < 0.1.

⁶ They include Beijing, Tianjin, Shanghai, Guangdong, Shenzhen, Hubei, and Chongqing.

Table 12

Robustness test — control time trend.

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
	<i>lncoal</i>	<i>lncoalint</i>	<i>lncoal</i>	<i>lncoalint</i>	<i>lncoal</i>	<i>lncoalint</i>
<i>after</i>	−0.2883** (0.112)	−0.2337*** (0.087)	−0.2935*** (0.108)	−0.2724*** (0.100)	−0.3295*** (0.115)	−0.3037*** (0.108)
<i>coalprice</i>	−0.0049** (0.002)	0.0010 (0.001)	−0.0033 (0.002)	0.0007 (0.002)	−0.0054* (0.003)	0.0009 (0.002)
Control variable	Yes	Yes	Yes	Yes	Yes	Yes
Time trend	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	136,585	136,585	136,585	136,585	103,963	103,963
R-squared	0.899	0.824	0.900	0.824	0.896	0.817

Robust standard errors in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

prices,⁷ as shown in columns (3) and (4). Third, most pilots are Non-resource-based areas, Non-coal-resource-based provinces maybe more sensitive to coal prices, so we drop Coal-resource-based provinces,⁸ only keep Non-resource-based areas' samples, and control coal price and time trend, get the results shown in column (5) and (6).

The results prove that our benchmark results are robust. After considering the possible influence of coal prices and different unobservable factors, which are different in the treatment group and control group, the coefficients of the policy effect on coal consumption and coal intensity are similar to those of the benchmark results. Moreover, the coefficients in columns (5) and (6) are a bit smaller than those of the benchmark results, which show more exact policy effect eliminating the interference of coal price on the policy effect of Non-coal-resource-based areas.

5. Conclusion

Under the pressure of controlling greenhouse gas emissions, governments have proposed many environmental regulations, and these regulations can be categorized into CAC regulations and market-based policies. Previous studies have different views on CAC environmental regulations; some prove that they hinder the growth in enterprise TFP, while others prove that they have significant environmental benefits. In this paper, employing a typical CAC environmental regulation—China's LCP city policy—we explore the effect of CAC environmental regulations on firms' coal consumption and coal intensity. Moreover, different from previous research, which has mainly studied the effects of China's LCP city policy at the regional level, we focus on the firm-level effect. Using firm-level data and adopting a DID model, we identify the change in within-sector energy efficiency and explore the heterogeneous effect.

Our main finding is that the LCP city policy reduces firms' coal consumption by almost 29% and reduces their coal intensity by almost 24%. In the heterogeneity analysis, we study different impacts on different industries, firms with different types of ownership, and different kinds of energy, and we find that the policy has a larger influence on energy-intensive industries. SOEs undertake more energy-saving tasks, and the dynamic effect analysis suggests that the policy effect decreases over time. Moreover, through parallel trend test and DDD analysis, we prove that our results are convinced. Furthermore, we use balanced observations, conduct a validity test based on the PSM-DID method, and control for the carbon trading pilot reform and time trend to prove that our results are robust.

Our findings provide empirical evidence for the energy-saving effect of CAC environmental regulations at the micro-level, which enriches the

existing literature that focuses on the region level or industry level. We prove that the LCP city policy not only decreases the total carbon emissions of regions but also can decrease firms' coal consumption and coal intensity, excluding the change in the regional industrial structure. Furthermore, we find that under administrative pressure from local governments, SOEs undertake more energy-saving targets. However, the CAC policy cannot have a long-term energy efficiency improvement effect. These results have some implications for developing countries that are in a similar position to China.

Even though we use a comprehensive database that contains energy consumption data to evaluate the LCP city policy effect from a micro-perspective, however, due to the lack of some variables, we cannot carry out in-depth mechanism analysis. Therefore, if more comprehensive data can be acquired, the potential effect of this CAC environmental regulation on enterprises' green innovation, research and development (R&D) and TFP can be further explored, as well as the potential effect on employment. In addition, evaluating the impact on air pollution is an interesting topic that could shed new light on CAC environmental policies.

CRedit author statement

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Acknowledgements

This work was supported by Key Laboratory of Mathematical Economics and Quantitative Finance, Ministry of Education, Guanghua School of Management, Peking University. This work was supported by grants from the National Social Science Foundation of China (Grant No. 19ZDA069) to L.T. G., the General Program of National Natural Science Foundation of China (Grant No. 72073142, 71873142) to H.F. N., and Special Funds of the National Natural Science Foundation of China (Grant No. 72141309) to H.F. N.

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⁷ The coal price data are from the Wind database.

⁸ We calculate the average coal production in the sample period and choose the province which produce over 100-million-ton raw coal, include Shanxi, Inner Mongolia, Shanxi, Guizhou, Xinjiang, Shandong, Henan, Anhui.

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