China Economic Review 59 (2020) 101351

Contents lists available at ScienceDirect

China Economic Review

journal homepage: www.elsevier.com/locate/chieco

The impact of energy regulation on energy intensity and energy structure: Firm-level evidence from China

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ARTICLE INFO

Keywords:
Energy regulation
Energy intensity
Energy structure

ABSTRACT

In this paper, we empirically investigate the impact of energy regulation on manufacturing firms' energy intensity and energy structure during 2003–2009. The identification uses the energy regulation of the 11th Five-Year Plan implemented in 2006. We show that tighter energy regulation leads to a significant energy intensity decrease and that firms switch their energy structure from using dirty fossil energy to a cleaner one. We also examine the mechanisms behind this phenomenon and find that the rising R&D inputs and increasing energy consumption ratio of high energy efficient firms are the mainly two reasons.

1. Introduction

Energy scarcity is a recurring topic. Over the last three decades, China's unprecedented economic growth has accompanied enormous energy consumption. In 2010, China's energy consumption was 3606 million tons of standard coal equivalent (tce), exceeding that of the United States for the first time. As Fig. 1 shows, after experiencing high growth stage, China's energy consumption appears to be stable and the share of energy consumption for the industrial sector has also fallen from 75% in 2000 to 67% in 2016. Meanwhile, Fig. 2 depicts the trend of Chinese energy intensity (tce per output) and energy consumption per capital. A number of patterns stand out. First, energy consumption per capita has almost tripled from 1.1 to 3.15 tce per capita due to rapid growth of Chinese economy. Second, energy intensity in China has been overall falling, from 13.91 to 10.23 kg coal equivalent per GDP (or about 25%), but it has rebounded during the period 2002–2005 and 2008. Industrial sector exhibits a similar trend in the two figures, except that the energy intensity of industrial sector is much higher than that of the whole. Albeit achieving a large decline, China's energy intensity in 2016 is still much higher than that of developed countries, even surpassing the world average by 50% as shown in Fig. 3. This means China still has considerable potential in saving its energy. A more disturbing problem for China is its unbalanced energy resource. Fig. 4 describes the changes of energy structure in China. We can learn that coal is in the dominating position in Chinese energy market. During 2000 to 2008, the coal consumption has even risen a little bit from 71.5% to 75%, which is due to the increasing demand of energy-intensive sectors such as steel. But since then, it has fallen to 66.7% in 2016. The share of oil has decreased steadily from 22.9% to 19.9%, while the share of natural gas and other energy (wind and water power) has continually improved, which suggests that China's energy structure has become cleaner. Undoubtedly, China has achieved an unneglectable step toward an energy-intensive country. It is important to figure out what drives the energy intensity reduction and cleaner energy use to help future policy enactment. In recent two decades, various regulations related to environment and energy has been launched and

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https://doi.org/10.1016/j.chieco.2019.101351
Received 30 December 2018; Received in revised form 12 June 2019; Accepted 17 September 2019
Available online 25 October 2019

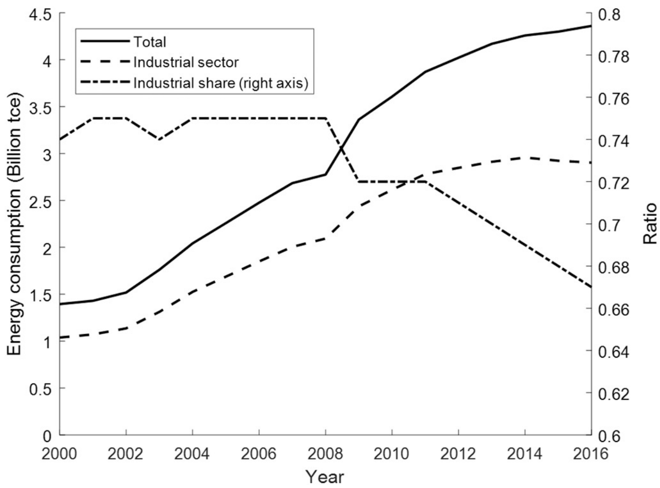

Fig. 1. Trend of energy consumption. Data Source: the China Energy Statistical Yearbook for 2001–2017.

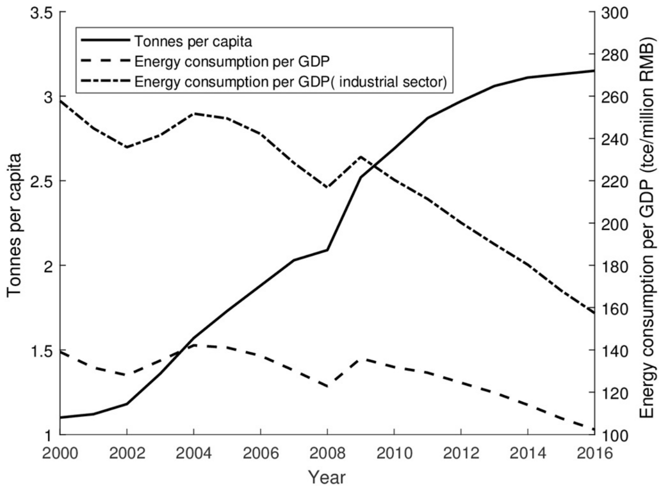

Fig. 2. Trend of energy consumption per capita and energy intensity. Data Source: the China Energy Statistical Yearbook for 2001–2017.

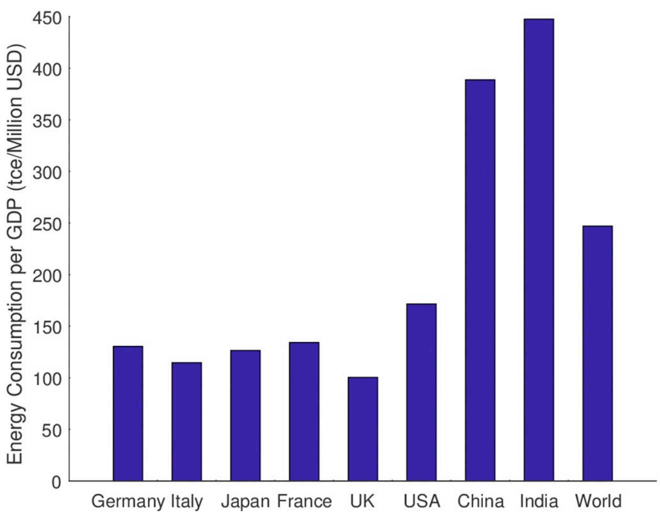

Fig. 3. Energy intensity of the major countries in 2016. Data Source: International Energy Agency Database.

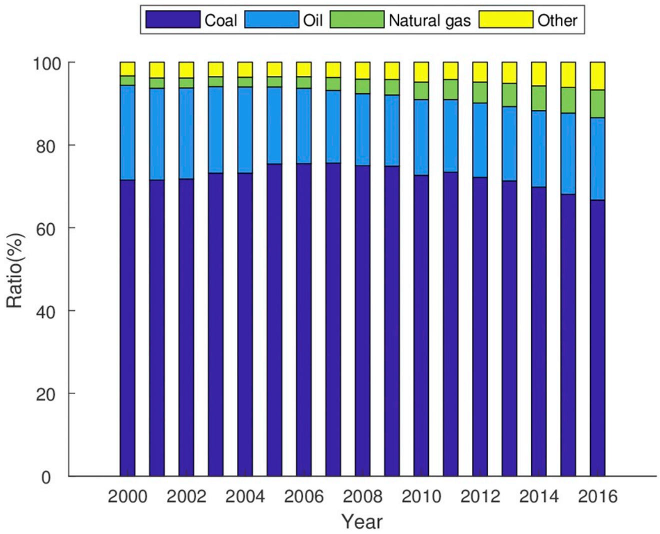

Fig. 4. Changes of energy structure Data Source: the China Energy Statistical Yearbook for 2001–2017.

correspondingly a large strand of literature studies whether those regulations are effective.

Through a forecasting framework Lin and Li (2015), find that environmental governance constraints can transform China's energy structure and thus CO_2 emissions and coal demand can be reduced. Chen and Cheng (2017) assess the Two Control Zones policy which restrict the SO_2 emissions in the target region. They find that the policy is inefficient for more polluting firms closing in targeted regions and opening in non-targeted regions. Chen, Kahn, Liu, and Wang (2018) study whether the 11th Five-Year Plan (FYP) was effective for controlling water pollutants. They find pollution-intensive activity decreases in areas with more stringent regulation and increases in lower regulated areas. Cai, Chen, and Gong (2016) also find that under China's pollution reduction mandate, water-pollution activities are shifted away to the most downstream counties. Although above literature conducts detailed analyses, most of them study the effect of environmental policy instead of energy regulation.

Several researchers assess the effect of Top-1000 energy-consuming enterprises program. Wang, Li, Song, and Ye (2015) evaluate the performance of iron and steel sector from 2006 to 2010 and find that the closing outdated facilities and more advanced technology are the main two reasons leading to energy saving. Ke et al. (2012) find that energy intensity decreases significantly during the 11th FYP period. Price, Wang, and Yun (2010) find that Top-1000 program works well and besides energy saving, it can also reduce CO_2 emissions by 450 Mt. However, due to data limitation, literature above only makes a descriptive analysis at the aggregate level. Shen, Zeng, and Qu (2015) analyze whether Top-1000 program has influence on firms' export performance and find that the program facilitates the export activities and increase firms' international competitiveness. But due to the lack of energy consumption data, they haven't analyzed whether the program is effective with respect to firms' energy intensity.

Another strand of literature focuses on the determinants of energy intensity. Higher energy price may motivate companies to reduce energy intensity (Cornillie & Fankhauser, 2004; Hang & Tu, 2007; Metcalf, 2008; Wing, 2008). By contrast, low energy price controlled by Chinese government is one of the main obstacles for energy intensity reduction (Zhao et al., 2009). Urbanization and industrialization also play significant roles in affecting energy intensity (Sadorsky, 2013). Meanwhile, Chinese past energy intensity reduction was mainly attributed to higher energy efficiency (Feng, Sun, & Zhang, 2009) and China still has much potencial to reduce energy intensity by transforming its energy structure (Liao, Fan, & Wei, 2007). Moreover, different sectors and regions exhibit heterogeneity in productivity improvement and environmental performance. Fujii, Jing, and Managi (2015) find that industrial wastewater emissions reduction in coastal areas, and economic performance improvement in the central and west regions are the main contributing factors of Chinese increasing productivity. Meanwhile, Technological innovation mainly takes place in the coastal provinces, and economic performance and environmental performance are negatively correlated in the west areas. Using a micro-level data, Fujii, Jing, and Managi (2016) further find the firm-level heterogeneity in corporate financial and environmental performance. A large number of technical innovators are found in the textile, paper, steel, and computer industries.

Although some literature above has studied the effect of government regulation or the factors influencing energy intensity, to the best of our knowledge, there is no literature quantitatively analyzing the effect of government regulation on energy intensity. Besides, mechanisms of how regulation influence firms' behavior are rarely analyzed in existing literature. This paper differs from previous literature in several dimensions.

First, we empirically exam the effect of government regulation on energy intensity and structure. The 11th (2006–2010) Five-Year Plan (FYP), as the first binding target for Chinese energy intensity, offers a compelling setting to exam the efficacy of Chinese energy regulations on energy intensity. In China, binding targets refer to the criteria through which central government assess the provincial governments' performance, just like KPI (Key Performance Indicator). The promotion of local officials is directly linked with whether they complete the binding targets. Although before 2006, there were several energy saving regulations, they were all not binding. Therefore before 2006, local officials actually had no incentive to fulfill those targets, which made it hard to assess regulation's efficacy. Besides, in the 11th FYP there was a national target of 20% energy intensity reduction, and central government decomposed it into the province-level targets. Generally, provinces with higher energy intensity were subject to higher reduction target. Local officers' promotion was also related to their compliance with these targets, which facilitate local governments to make efforts to meet these targets. In addition, the Chinese FYPs are one of the most important development guidelines. Several subprojects, such as the Top-1000 Program, were also implemented to help achieving this plan. All the programs and plans indicate China's resolute determination in energy saving and energy transformation. Besides the 11th FYP, we also construct the environmental-related word ratio of government work reports as the proxy of energy regulation to do a robustness test.

Second, this paper pays much attention to the mechanisms of how energy regulation influences energy intensity. Energy intensity is directly correlated with firms' productivity. And according to Baily, Hulten, Campbell, Bresnahan, and Caves (1992) and Melitz and Polanec (2015), change in aggregate productivity can be decomposed into within-firm effect and between-firm effect. The former effect emphasizes the technological improvement of the enterprise itself. The latter effect comes from two mainly sources: market share reallocation among surviving firms, and the entry of new producers and the exit of old ones. Following this way, we decompose the reduction of firm's energy intensity into three components: technological improvement of firms themselves, selection dynamics and energy share reallocation. With respect to the technological improvement channel, energy regulation will encourage firms to develop green and more efficient technology and thus decrease their energy intensity. The selection dynamics channel indicates that energy regulation may encourage the entry of new producers which have lower energy intensity and the exit of old ones which have higher energy intensity. Energy share reallocation may also contribute to the aggregate reduction of energy intensity if those high energy efficient firms consume more energy relative to the low ones. Therefore, we test whether the energy regulation influence firms' energy intensity through the three channels above.

Third, this paper presents a systematic evaluation of China's energy regulations with a new firm-level panel dataset for the years 2003–2009. We collect the direct data of firm-level energy consumption, including the consumption of coal, oil and natural gas, and investigate how firms react to the stricter energy regulations. To the best of our knowledge we are unaware of a comparable dataset in existing literature.

This paper, using a difference-in-differences method, investigates the impact of the 11th FYP's binding target on energy intensity reduction and fills the gap in previous literature. Significant evidence shows that more stringent regulation leads to lower energy intensity and less coal consumption. We also analyze the mechanisms behind this phenomenon. For the within-firm effect, we find that the 11th FYP significantly encourages firms' investment in R&D and thus promote firm's productivity and reduce energy intensity. As for the between-firm effect, the mechanism of market share reallocation is proved by the estimated results while the mechanism of selection dynamics is not at work. Brandt, Van Biesebroeck, Wang, and Zhang (2017) suggests that state-owned firms face softer budget constraints. In this paper, we also find the similar pattern that non-state-owned firms outperform state-owned firms under energy regulations and that firms with high energy consumption reduce their energy intensity more than firms with low energy consumption.

The remainder of this paper is organized as follows: Section 2 describes the background information about Chinese energy regulation; Section 3 introduces the data and the econometric methodology; Section 4 presents the regression results; Section 5 discusses the potential mechanisms; Section 6 conducts heterogeneity analysis; Section 7 do some robustness checks and Section 8 concludes.

2. Institutional background

China has a decentralized political system. Normally central government will set a general target and provincial governments are responsible for enacting detailed regulations to fulfill these specific targets which central government sets. In every 5 years, central government would publish a FYP which specifies the targets for the next 5 years. These targets mainly include GDP and population growth rate, unemployment rate, inflation rate, etc. However, there are two types of these targets. Some are binding targets and the others are expecting targets. The FYPs' binding targets are one of the most crucial criteria for evaluating local governments' performance and local officials' promotion is directly linked with the completion of binding targets. The center government announces that local officials will receive administrative demerit recording or be removed from office if they fail to meet the binding targets. Hence local governments have weaker incentive to achieve the expecting targets compared to the binding ones.

To recover deteriorative environment and to save energy, central government published several relevant policies among which FYPs are the most crucial. In the 9th (1996–2000) FYP, Chinese central government added an annual 5% reduction expecting target of energy intensity for the first time, and subsequently China realized an annual 6.1% energy intensity reduction. The 10th (2001–2005) FYP which also set up the total 10% energy intensity reduction expecting target, nonetheless failed, which can be seen in Fig. 2. In fact, no matter how much China has achieved in energy saving, before 2005, all the targets about energy saving are not the binding targets, which suggests that local officials have weak incentives to fulfill these targets. By contrast, instead of focusing on energy saving and environmental protection projects, local officials would rather build industrial plants in order to generate local fiscal revenue and fulfill the GDP targets, which are more closely related to their promotion. That may explain why energy intensity during 2001–2005 even rose. Realizing the severe situation of both the environment and energy, central government included energy intensity reduction as the binding target in the 11th FYP for the first time.

In March 2006, the 11th FYP is released and China is supposed to achieve a binding target of total 20% national energy intensity reduction and a package of sub plans are carried out including Top-1000 enterprises program, Ten major energy conservation projects and so on. Meanwhile, GDP growth was defined as expecting targets, suggesting that local officials had less incentive to increase GDP at the sacrifice of energy abuse. In September 2006, the national State Council decomposes the national binding target into the province-level targets, which are shown in Appendix Table A1. In this plan, provinces with high energy intensity are exposed to more pressure of energy intensity reduction, such as Shanxi and Jilin, while provinces with low energy intensity face lower pressure, such as Hainan and Guangdong. In this way, stringency of the energy regulation is different among provinces and we use the variance of the reduction targets to represent the regulation stringency.

Since there are several ways for Chinese government to implement its regulation, including adjusting pollution tax, raising R&D, or enacting certain laws, using a single index as the proxy for energy regulation may be biased. To measure energy regulation comprehensively, we also construct another variable that is the environmental related word ratio of each province's government work report and use it as the proxy of energy regulation for our robustness check.

3. Data and method

3.1. Econometric methodology

Our main objective of this paper is to identify whether the 11th FYP has effect on energy intensity or energy structure. In the 11th FYP, provinces which previously have larger energy intensity generally suffer higher binding targets, such as Inner Mongolia and Shanxi, and provinces whose energy intensity is already low, suffering lower binding targets (e.g. Hainan and Guangdong), which allows us to conduct a difference-in-differences (DD) estimation. The estimation is to compare the change in firms' energy intensity reduction in previous high energy intensity provinces (the treatment group) before and after the 11th FYP to the corresponding change in previous low energy intensity provinces (the control group). We expect that provinces suffered from more regulation pressure will have higher incentive to reduce energy intensity. Based on the above discussion of the 11th FYP, we estimate the DD model specification as:

$$Y_{i,t} = \beta Regulation_p \times Post_t + X'_{i,t}\theta + \gamma_t + \eta_c + \alpha_d + \lambda_i + \varepsilon_{i,t} \quad (1)$$

where subscripts *i, t, p, c* and *d* denote firm, year, province, city and 2-digit industry, respectively. *Y* represents the logarithm of energy intensity (energy consumption per unit of output) or energy ratio of each fuel type (coal, oil and natural gas). *X′* is a vector of firm characteristics that influence a firm's energy intensity, including capital, debt, employment, firm age and export state. *Regulation* is a measure of regulation stringency and we use each province's reduction rate of energy intensity to approximate it (see in Appendix Table A1). *Post* is a dummy variable which indicates the post-treatment period. It equals one when $t > 2006$, otherwise it equals zero. η_c, α_d and λ_i stand for city, 2-digit industry and firm fixed effects, respectively, denoting all permanent unobservable influences across cities, 2-digit industries and firms; γ_t, the year fixed effects, represent the unobservable changing environment, such as monetary and fiscal policies, business cycle and macro shocks; ε remains the error term.[1]

The coefficient which we care about is the β. Its sign can indicate whether provinces facing stricter energy regulation reduce more of their energy intensity or inhibit more coal consumption. To match what is frequently done in DD estimation, the standard errors are clustered at the city-level.

3.2. Data

Our first data source is the China Environmental Statistics Dataset from 2003 to 2009, which contains firm's energy consumption of each fuel type (coal, oil and natural gas) and to the best of our knowledge, existing literature didn't utilize such micro dataset. This paper's dependent variables, energy intensity and energy structure are calculated based on this dataset. As for the control variables including capital, employment, debt, age, export and R&D investment, we need to match the previous dataset with the Annual Survey of Industrial Firms (ASIF) conducted by the National Bureau of Statistics (NBS), which includes basic information about all state-owned or non-state-owned industrial firms with revenue above 5 million RMB. Finally, we get the unbalanced panel which contains 277,028 observations. As for the robust check, just like Chen and Chen (2018), each province's government work report can be easily downloaded from official website and instead of just counting the number of environmental related words, we use R program to separate the words in the government work reports and then calculate the environmental-related word ratio, which makes the ratio more precise and reliant. Appendix Fig. A1 describes the kernel density of word ratio for 2004, 2006 and 2008. Table 1 summarizes the descriptive statistics of relevant variables used in our econometric model. On average, coal is in the dominating position of firms' energy structure and oil consumption is about twice the consumption of natural gas. The mean value of R&D is 0.069, suggesting that only a few firms invest in R&D.

4. Main results

4.1. The impact of energy regulation on energy intensity

Table 2 shows our estimated effect of energy regulation on manufacture enterprises' energy intensity based on Eq. (1). In this table, the outcome is the logarithm of energy intensity that firm faces, calculated by each firm's total energy consumption divided by

[1] During our sample period, there exists 2212 samples change their locations at the city level. And 17,493 samples change their industry type at the 2-digit industry level. So, besides firm fixed effects, it's necessary to control city and industry fixed effects in our regression model.

Table 1
Summary statistics.

Variable	Unit	Obs.	Mean	Std. dev.	Min	Max
Energy intensity	tce/ten thousand yuan	305,633	0.389839	0.647425	0	4.992192
Coal ratio	%	223,851	0.869448	0.327282	0	1
Oil ratio	%	223,851	0.089442	0.275871	0	1
Natural gas ratio	%	223,851	0.041111	0.190822	0	1
Capital/employment	thousand yuan per person	307,670	0.040382	0.064117	1.67E-07	0.998286
Debt/capital		307,670	0.601814	0.302563	0	3
Employment	person	307,670	5.372578	1.176362	0.693147	11.9823
Age	year	307,670	12.79976	13.38912	0	120
Export	dummy	302,547	0.27409	0.446055	0	1
Report ratio	%	273,419	0.005451	0.002052	0.001176	0.011859
R&D	dummy	307,670	0.069198	0.25379	0	1
R&D expenditure		307,670	0.433642	1.704626	0	14.31434
Exiter		307,670	0.169042	0.374789	0	1
Entrant		307,670	0.051981	0.221989	0	1

Notes: Export equals one if a firm exports commondities and R&D equals 1 if a firm invests in R&D. R&D expenditure represents the logarithm of one plus the R&D expenditure. Exiter equals one when a firm is only observed in the dataset before this year or it equals zero. Entrant equals one when a firm is observed in the dataset for the first time. Data Source: the China Environmental Statistics Dataset for 2003–2009, the China Industry Business Performance Dataset for 2003–2009.

Table 2
The Impact of energy regulation on energy intensity.

Variables	(1)	(2)	(3)
	Energy intensity	Energy intensity	Energy intensity
Regulation*post	−0.8465***	−0.8455***	−0.5803***
	(0.0590)	(0.0492)	(0.2056)
Capital labor ratio		−0.1267**	−0.1680***
		(0.0546)	(0.0357)
Debt capital ratio		0.1856***	0.0337***
		(0.0138)	(0.0062)
Employment		0.0141***	−0.0454***
		(0.0049)	(0.0054)
Firm age		−0.0002	0.0000
		(0.0004)	(0.0001)
Export		−0.3304***	−0.0165***
		(0.0139)	(0.0051)
Firm fixed effects	No	No	Yes
Year fixed effects	No	No	Yes
Industry fixed effects	No	No	Yes
City fixed effects	No	No	Yes
Observations	305,633	300,510	277,028
R-squared	0.0155	0.0738	0.8756

Notes: *** stands for $p < 0.01$, ** stands for $p < 0.05$, and * stands for $p < 0.1$. Robust standard errors are reported in parentheses. Data Source: the China Environmental Statistics Dataset for 2003–2009, the China Industry Business Performance Dataset for 2003–2009.

the firm's total output. The types of energy used by a firm in the production process include coal, oil and natural gas. We convert them to standard coal and add them up. In column (1), we only include *Regulation*Post* which are our regressor of interest (energy regulation) and city and year fixed effects. The coefficient of the regressor is statistically significant and negative, suggesting that manufacture enterprises' energy intensity decreases more as energy regulation become stricter.

In column (2), we add some time-varying firm characteristics that may be correlated with both our outcome variable (energy intensity) and our regressor of interest (energy regulation). These variables include firm's capital labor ratio, debt capital ratio, employment which stands for the scale of the firm, firm age and the dummy variable of whether the firm is an exporter. Evidently, our regression results are still robust. We also include firm fixed effects and industry fixed effects to capture unobservable information that does not change with time within firm and industry. Column (3) shows the results including these fixed effects and the coefficients of our interest remain negative and statistically significant.

In the following part, we will do some robustness check on the identifying assumption of the difference-in-differences model we mainly applied in this paper.

4.1.1. Parallel trend assumption

The underlying assumption for an unbiased estimate in difference-in-differences model is that the trends in the outcomes for both control and treatment group prior to the implementation of the energy regulation related to energy saving in the 11th FYP are

Table 3
Checks on the identification assumptions.

Variables	(1)	(2)	(3)
	Energy intensity	Energy intensity	Energy intensity
Regulation*post		−0.6205**	−0.6081**
		(0.2399)	(0.2556)
Regulation*one year before Regulation implementation		−0.0993	
		(0.1887)	
Regulation*year dummy 2004	−0.4091		
	(0.3558)		
Regulation*year dummy 2005	−0.3366		
	(0.3552)		
Regulation*year dummy 2006	−0.4632		
	(0.3661)		
Regulation*year dummy 2007	−0.9181**		
	(0.3616)		
Regulation*year dummy 2008	−1.1614***		
	(0.4091)		
Regulation*year dummy 2009	−1.0574**		
	(0.4334)		
Capital labor ratio	−0.1641***	−0.1679***	−0.1383**
	(0.0345)	(0.0357)	(0.0688)
Debt capital ratio	0.0333***	0.0337***	0.0251**
	(0.0045)	(0.0062)	(0.0122)
Employment	−0.0454***	−0.0455***	−0.0264***
	(0.0043)	(0.0054)	(0.0078)
Firm age	0.0000	0.0000	0.0003*
	(0.0001)	(0.0001)	(0.0002)
Export	−0.0165***	−0.0164***	−0.0162***
	(0.0043)	(0.0051)	(0.0053)
Firm fixed effects	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes
City fixed effects	Yes	Yes	Yes
Observations	277,028	277,028	66,368
R-squared	0.8757	0.8756	0.8567

Notes: *** stands for $p < 0.01$, ** stands for $p < 0.05$, and * stands for $p < 0.1$. Robust standard errors are reported in parentheses. Column (1) tests whether the regulation affect firms' energy intensity before 11th FYP. For example, the statistically insignificant coefficient of dummy 2004 indicates that there is no regulation in 2004 affecting energy intensity. In Column (2), we test whether the expectation effect (Regulation*One year before) exists. In Column (3), we only include firms existing within the same province throughout the sample period 2003–2009. Data Source: the China Environmental Statistics Dataset for 2003–2009, the China Industry Business Performance Dataset for 2003–2009.

parallel. The 11th FYP was conducted in 2006, so we test the parallel pretreatment trends assumption using an event study approach (Jacobson, Lalonde, & Sullivan, 1993). The specification is given by:

$$Y_{i,t} = \sum_{k=-2}^{3} Regulation_p * Year_{2006+k}\beta_k + X'_{i,t} + \gamma_t + \eta_c + \alpha_d + \lambda_i + \varepsilon_{i,t} \tag{2}$$

In Eq. (2), $Y_{i,\ t}$ represents energy intensity in firm *i* and year *t*. $Regulation_p$ represents the degree of energy regulation in the 11th FYP. $Year_{2006+k}$ represents the calendar year dummies. Note that 2003 is omitted in Eq. (2), so that the posttreatment effects are relative to the first year of our sample period. We include the leads of the energy regulation dummy in the equation, testing whether the regulation affects firm's energy intensity before the energy regulation in the11th FYP.

The result is reported in Column (1) of Table 3. To help visualize the dynamic effect, the point estimates β_k of Eq. (2) along with their 90% confidence intervals are shown in Panel A of Fig. 5. As indicated in this figure, point estimates are statistically insignificant at the conventional level before the following year of the energy regulation taking effect ($k < 1$). After the next year at which time the regulation policy become effect ($k \geq 1$), the point estimates β_k become statistically significant and increasing negative. The result is consistent with the parallel trends assumption inherent in our difference-in-differences analysis and adds support for the following empirical analysis based on this method.

4.1.2. Expectation effect

In Column (2) of Table 3, we add an additional control variable, *Regulation* One year before Regulation Implementation*, to check whether firms change their behavior in anticipation of the energy regulation coming into effect. If there exists expectation effect, our treatment and control groups will not be comparable, and our estimation results will be biased. The coefficient of *Regulation* One year before Regulation Implementation* is found to be statistically insignificant， which means there exists little expectation effect. Moreover, the coefficient of our interest, *Regulation*Post*, is still negative and statistically significant.

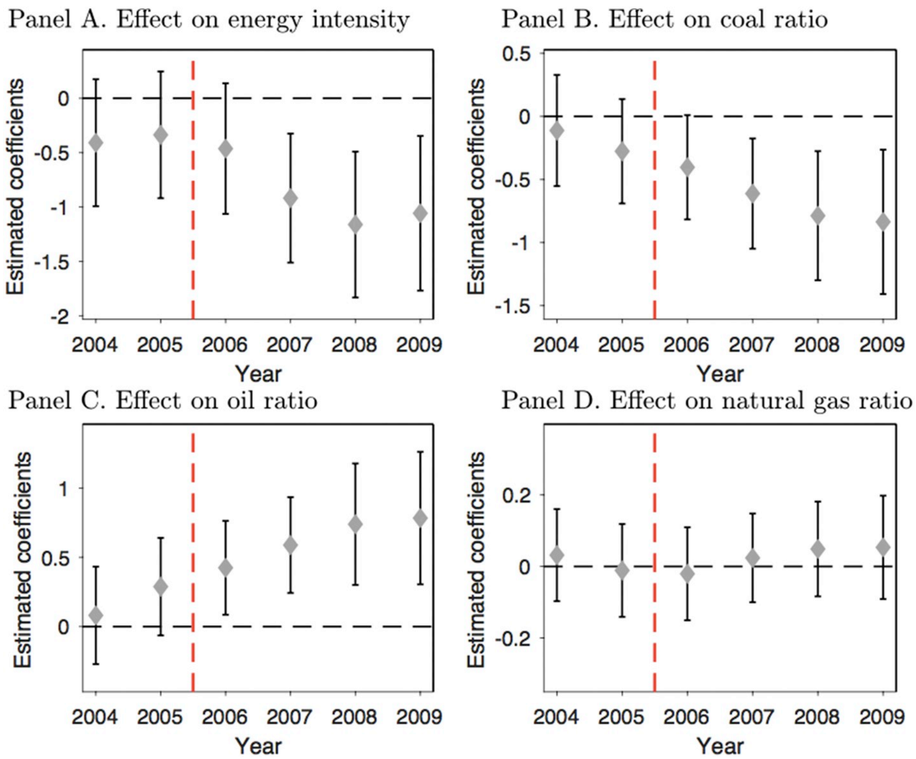

Fig. 5. Estimated effect of implied energy regulation for years before and after actual treatment. Notes: This graph presents the results of the test of parallel trend assumption, which exams whether the regulation affects firm's energy intensity and structure before or after the energy regulation in the Eleventh Five-Year Plan. The four subgraphes separately depicts the coefficients along with their 90% confidence intervals with respect to energy intensity, coal ratio, oil ratio and natural gas ratio. Data Source: the China Environmental Statistics Dataset for 2003–2009, the China Industry Business Performance Dataset for 2003–2009.

Firms Existing Before and After the 11th FYP. Stricter energy regulation following the 11th FYP may induce firms to exit the market or move to other provinces with relatively weaker energy regulation, leading to bias our estimation results. To address this problem, we restrict our sample to firms existing within the same province throughout the sample period 2003–2009. Then we conduct the same analysis, the coefficient of our interest shown in Column (3) of Table 3 experiences very little change and remains statistically significant.

4.2. The impact of energy regulation on energy structure

In this section, we examine the effect of energy regulation on firms' energy structure. After the implementation of the 11th FYP, will firm switch their energy structure from using dirty fossil energy (i.e., coal) to a cleaner one (i.e., oil or natural gas)? We use three variables to measure a firm's fossil energy structure: the ratio of coal, oil and nature gas consumption respectively. Table 4 shows our estimated effect of energy regulation on manufacture enterprises' energy structure. As indicated in Column (1), the coefficient of energy regulation is negative and statistically significant, indicating that the implementation of the energy policy lead manufacture enterprises to change their energy structure and use relatively less dirty energy (coal). Column (2) presents the result of the effect of energy regulation on firm's oil consumption ratio, the coefficient of *Regulation*Post* is positive and still statistically significant, implying that firms which face stricter energy regulations use more relatively cleaner fossil energy (oil). Column (3) shows that energy regulation has positive effect on the ratio of firm's natural gas, but the coefficient is statistically insignificant.

An important assumption of our difference-in-differences model is that the over-time changes in outcomes across firms are caused by the energy regulation implemented in 2006, not by any pre-existing differential time trends across comparison firms. Table 5 present the estimated yearly effect of energy regulation on firms' energy structure (coal ratio, oil ratio and nature gas ratio). To help visualize the dynamic effect, the point estimates are shown in Panel B, C and D in Fig. 5. As indicated in both the table and the figure, point estimates are statistically insignificant at conventional levels before 2006, which means that the pre-existing time trends across comparison firms are parallel.

5. Channels at work

Our explanation for the main results is that energy regulation leads to the decrease of firms' energy intensity and transforms firms'

Table 4
The impact of energy regulation on energy structural.

Variables	(1)	(2)	(3)
	Coal ratio	Oil ratio	Natural gas ratio
Regulation*post	−0.4781***	0.4638***	0.0144
	(0.1663)	(0.1606)	(0.0483)
Capital labor ratio	−0.0353*	0.0068	0.0286**
	(0.0195)	(0.0197)	(0.0134)
Debt capital ratio	−0.0011	0.0016	−0.0005
	(0.0020)	(0.0017)	(0.0015)
Employment	0.0026	−0.0051**	0.0026*
	(0.0024)	(0.0022)	(0.0014)
Firm age	0.0001	−0.0001	−0.0000
	(0.0001)	(0.0001)	(0.0001)
Export	−0.0017	−0.0006	0.0023
	(0.0020)	(0.0015)	(0.0015)
Firm fixed effects	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes
City fixed effects	Yes	Yes	Yes
Observations	202,115	202,115	202,115
R-squared	0.9188	0.9103	0.8490

Notes: *** stands for $p < 0.01$, ** stands for $p < 0.05$, and * stands for $p < 0.1$. Robust standard errors are reported in parentheses. Data Source: the China Environmental Statistics Dataset for 2003–2009, the China Industry Business Performance Dataset for 2003–2009.

Table 5
Test for the parallel trend assumption of energy structural.

Variables	(1)	(2)	(3)
	Coal ratio	Oil ratio	Natural gas ratio
Regulation*year dummy 2004	−0.1121	0.0806	0.0315
	(0.2685)	(0.2147)	(0.0785)
Regulation*year dummy 2005	−0.2767	0.2879	−0.0112
	(0.2525)	(0.2148)	(0.0791)
Regulation*year dummy 2006	−0.4035	0.4242**	−0.0206
	(0.2523)	(0.2066)	(0.0793)
Regulation*year dummy 2007	−0.6121**	0.5883***	0.0238
	(0.2664)	(0.2110)	(0.0756)
Regulation*year dummy 2008	−0.7877**	0.7389***	0.0488
	(0.3121)	(0.2673)	(0.0808)
Regulation*year dummy 2009	−0.8364**	0.7831***	0.0533
	(0.3490)	(0.2918)	(0.0881)
Capital labor ratio	−0.0320**	0.0039	0.0281**
	(0.0136)	(0.0115)	(0.0110)
Debt capital ratio	−0.0013	0.0018	−0.0005
	(0.0014)	(0.0011)	(0.0010)
Employment	0.0025	−0.0051***	0.0025***
	(0.0015)	(0.0013)	(0.0009)
Firm age	0.0001	−0.0001	−0.0000
	(0.0001)	(0.0000)	(0.0001)
Export	−0.0017	−0.0006	0.0023*
	(0.0018)	(0.0015)	(0.0013)
Firm fixed effects	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes
City fixed effects	Yes	Yes	Yes
Observations	202,115	202,115	202,115
R-squared	0.9189	0.9105	0.8490

Notes: *** stands for $p < 0.01$, ** stands for $p < 0.05$, and * stands for $p < 0.1$. Robust standard errors are reported in parentheses. Column (1), (2), (3) test whether the regulation affect firms' coal, oil and natural gas ratio before 11th FYP respectively. For example, the statistically insignificant coefficient of dummy 2004 in column (1) indicates that there is no regulation in 2004 affecting firms' coal ratio. Data Source: the China Environmental Statistics Dataset for 2003–2009, the China Industry Business Performance Dataset for 2003–2009.

Table 6
Channels at work.

Variables	(1)	(2)	(3)	(4)	(5)	(6)
	R&D	R&D expenditure	Energy intensity	Energy intensity	Exit	Entry
Regulation*post	0.0014**	0.0097*			−0.0004	−0.0019
	(0.0007)	(0.0053)			(0.0019)	(0.0014)
R&D			−0.0142***			
			(0.0032)			
R&D expenditure				−0.0021***		
				(0.0004)		
Capital labor ratio	0.0685***	0.6227***	−0.1734***	−0.1731***	0.0401	−0.1406***
	(0.0237)	(0.1631)	(0.0364)	(0.0364)	(0.0342)	(0.0231)
Debt capital ratio	−0.0000	0.0121	0.0337***	0.0337***	0.0336***	−0.0268***
	(0.0032)	(0.0208)	(0.0062)	(0.0062)	(0.0062)	(0.0043)
Employment	0.0085***	0.0805***	−0.0452***	−0.0452***	−0.0545***	−0.0277***
	(0.0020)	(0.0137)	(0.0054)	(0.0054)	(0.0045)	(0.0023)
Firm age	−0.0002*	−0.0018*	0.0001	0.0001	0.0006***	−0.0035***
	(0.0001)	(0.0010)	(0.0001)	(0.0001)	(0.0001)	(0.0002)
Export	0.0070*	0.0514	−0.0166***	−0.0166***	−0.0065	−0.0121***
	(0.0042)	(0.0314)	(0.0051)	(0.0051)	(0.0050)	(0.0026)
Firm fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
City fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	279,022	279,022	277,028	277,028	279,022	279,022
R-squared	0.4659	0.4763	0.8756	0.8756	0.3478	0.4334

Notes: *** stands for $p < 0.01$, ** stands for $p < 0.05$, and * stands for $p < 0.1$. Robust standard errors are reported in parentheses. R&D is the dummy of whether a firm invest in R&D. R&D expenditure is the logarithm of firm's R&D expenditure plus one. Exiter equals one when a firm is only observed in the dataset before last year or it equals zero. Entrant equals one when a firm is observed in the dataset for the first time. Data Source: the China Environmental Statistics Dataset for 2003–2009, the China Industry Business Performance Dataset for 2003–2009.

energy structure to a cleaner one. In this section, we examine alternative explanations and discuss potential mechanisms.

Baily et al. (1992) and Melitz and Polanec (2015) reveal that change in aggregate productivity can be decomposed into within-firm effect and between-firm effect. The within-firm effect emphasizes the technological innovation of the enterprise itself. And the between-firm effect is due to two sources: the changes in market shares among surviving firms and the entry of new producers and the exit of old ones. Following this method, we decompose the change of firm's energy intensity into three components: technological improvement of firm itself, selection dynamics and energy share reallocation. As for the technological innovation channel, energy regulation will encourage firms to innovate efficient technology and lower their energy intensity. The selection dynamics channel reveals that energy regulation may induce the entry of new producers which own lower energy intensity and the exit of old ones which have higher energy intensity. Energy share reallocation may exist between firms, those high energy efficient firms will consume more fossil energy relative to the low energy efficient firms. In the following part of this section, we will examine these mechanisms.

5.1. Technological innovation channel

Given that Annual Survey of Industrial Firms (ASIF) dataset does not include any direct measure about the technological improvement of a firm and technological innovation is highly related with the R&D inputs, we utilize firms' R&D inputs to represent the degree of technological innovation. Specifically, we use the dummy of whether a firm invest in R&D and the logarithm of one plus firm's R&D expenditure to stand for R&D inputs. Column (1) and (2) of Table 6 present our estimated effect of energy regulation on firm's R&D inputs. Estimators of our interest are positive and statistically significant, indicating that strict energy regulation policies motivate firms' R&D inputs and result in technological innovation. The results of Column (3) and (4) reveal that R&D inputs have a negative effect on firms' energy intensity. Combining the results from Column (1) to (4), we can conclude that within firms' technological innovation is an important mechanism cutting down firms' energy intensity.

5.2. Selection dynamics channel

Firm's entry and exit is another channel that may influence energy intensity. If high energy intensity firms are more likely to exit the market and new entrants own low energy intensity under the pressure of energy regulation, the energy intensity of overall manufacturing firms will be reduced. The long-time period of our dataset allows us to examine this channel. Similar to Disney et al. (2010) and Zhou, Zhang, Gu, and Jiang (2006), we denote entry as the first year that a firm is observed in the dataset, and the exit is

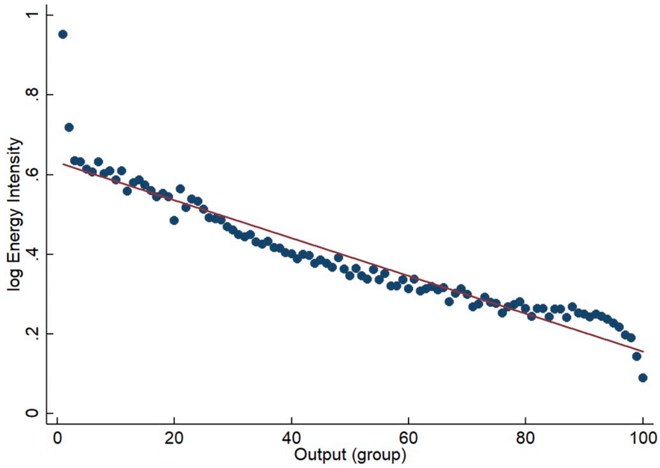

Fig. 6. The relationship between firm scale (output) and energy intensity. Notes: This figure indicates that with the increase of firm scale, the energy intensity tends to decrease. It proves that the energy consumption of bigger firms is more effective than small firms.

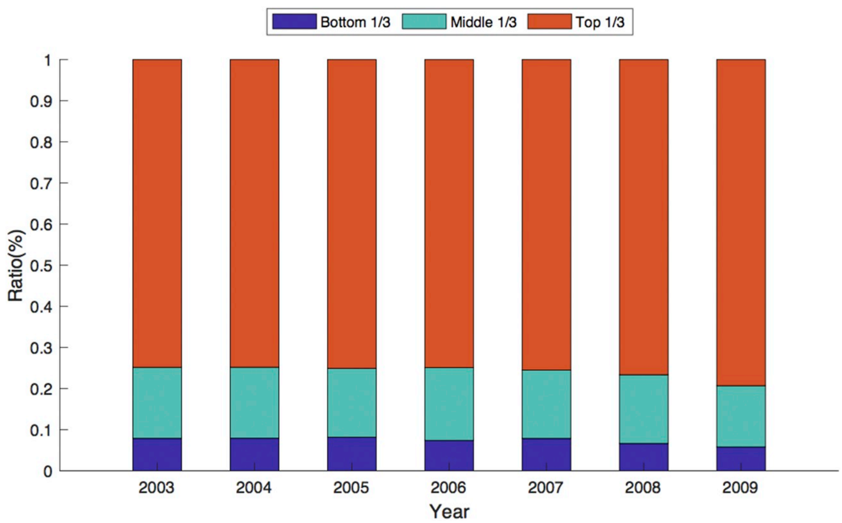

Fig. 7. Market share reallocation Notes: each year, we divide all firms equally into three groups by their gross output. For example, firms in Top 1/3 mean that outputs of those firms rank first third. The ratios in vertical axis represent represtent market shares of energy consumption with respect to firms of Top 1/3, Middle 1/3 and Bottom 1/3.

defined as a firm is only observed before this year in the dataset.[2]The results of energy regulation's effect on firms' entry and exit are shown in Column (5) and (6) of Table 6. Both the coefficients are negative and statistically insignificant, indicating that market dynamics through entry and exit is not an important mechanism influencing firms' energy intensity.

5.3. Energy share reallocation channel

Previous literature presents that energy regulation can increase the degree of industrial agglomeration and leave larger firms in the market (Xiong & Deng, 2017). If the energy intensity of large firms is smaller than small firms, the mechanism of energy share reallocation can help lowering down overall energy intensity. Fig. 6 depicted the relationship between firm scale and energy intensity. It indicates that with the increase of firm scale, the energy intensity tends to decrease. It proves that the energy consumption of big firms is more effective than small firms. To examine whether larger firms' share of energy are increasing throughout the period 2003–2009, we divide all firms equally into three groups by their gross output. Fig. 7 shows the evolution of each groups' energy

[2] Due to the limitation of the dataset, our definition is a little bit different with the real definition of firm entry and exit. But this definition is also meaningful and we only focus on the firms included in the ASIF dataset. The dataset contains the most of the industrial output in China. If a firm is born before it enters into the dataset or still alive when it was not included in the dataset, we believe its scale is too small and it's not very important to our research, because we only focus on those firms whose scale is large enough.

Table 7
Heterogeneity analysis.

Variables	(1)	(2)	(3)	(4)
	Energy intensity	Energy intensity	Energy intensity	Energy intensity
	Stated-owned	Non-stated-owned	High energy dependence	Low energy dependence
Regulation*post	−0.1564	−0.8007***	−0.0054**	−0.0016***
	(0.2183)	(0.2370)	(0.0023)	(0.0004)
Capital labor ratio	−0.0368	−0.2011***	−0.3797***	−0.0167
	(0.0852)	(0.0419)	(0.0586)	(0.0107)
Debt capital ratio	0.0406***	0.0286***	0.0563***	0.0019
	(0.0118)	(0.0076)	(0.0076)	(0.0018)
Employment	−0.0631***	−0.0400***	−0.1282***	−0.0096***
	(0.0114)	(0.0057)	(0.0067)	(0.0012)
Firm age	0.0003	−0.0000	0.0002	0.0000
	(0.0002)	(0.0002)	(0.0002)	(0.0000)
Export	−0.0416***	−0.0102**	−0.0299***	−0.0014
	(0.0123)	(0.0048)	(0.0073)	(0.0012)
Firm fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes
City fixed effects	Yes	Yes	Yes	Yes
Observations	57,625	205,238	136,570	129,162
R-squared	0.9079	0.8700	0.8852	0.8043

Notes: *** stands for $p < 0.01$, ** stands for $p < 0.05$, and * stands for $p < 0.1$. Robust standard errors are reported in parentheses. High energy dependence includes firms whose energy consumption per output was above the whole sample median in 2005, while low energy dependence includes the rest. Data Source: the China Environmental Statistics Dataset for 2003–2009, the China Industry Business Performance Dataset for 2003–2009.

share during our sample period. The energy share of the top 1/3 firms are increasing steadily, while the share of middle 1/3 and bottom 1/3 firms are decreasing. This phenomenon coincides with our energy share reallocation channel.

Overall, energy regulation may have caused a decline in Chinese manufacture firms' energy intensity via two channels: within firms' technological innovation and between firms' energy share reallocation.

6. Heterogeneity analysis

Our aforementioned analysis estimates the average effect of energy regulation on firms' energy intensity and the underlying mechanisms that can account for energy regulation's negative effect on energy intensity. In this section, we investigate the heterogeneous effects of energy regulation on energy intensity across firms to further shed light on how energy intensity is affected by energy regulation.

6.1. Stated-owned firms vs. non-stated-owned firms

Jiang, Lin, and Lin (2014) find that state-owned enterprises (SOEs) emit more intensive pollutant. Moreover, exports of privately-owned firms are found to be negatively influenced by the environmental regulation while SOEs seem to be unaffected, which is in accordance with the theory that China has preferential treatment toward SOEs (Hering & Poncet, 2014). To investigate whether firm ownership is important in determining the effect of energy regulation on firm's energy intensity, we follow the work of Huang et al. (2017). A stated-owned firm is defined as the share ratio of stated ownership is exceeding 30%. In Column (1) and (2) of Table 7, we estimate the coefficients by firm ownership type and find that the decline of energy intensity is driven mainly by non-stated-owned firms. Energy regulation has no significant effect on stated-owned firms. There may exist two reasons underlying this phenomenon. One possible explanation is that stated-owned firms have greater bargaining power over local governments and face more loosely energy regulation. Another reason is that state-owned firms may have better energy performance relative to non-stated-owned firms before the implementation of energy regulation, so they are not affected by the regulation policy. However, based on our dataset, we can find that the average energy intensity of the stated-owned firms is 1.98, which is bigger than non-stated-owned firms (1.42). The result indicates that the most likely reason is that energy regulation is not binding for stated-owned firms.

6.2. Firms of high-energy dependence vs. low-energy dependence

It's possible that firms relying heavily on fossil energy may have been more likely to be regulated by local governments and their energy intensity decreases more. To investigate this possibility, firms are categorized based on whether their average fossil energy consumption per unit output in 2005 was above or below the sample median. The differential impacts between high-energy de-

Table 8
Testing for concurrent events.

Variables	(1)	(2)	(3)	(4)
	Energy intensity	Coal ratio	Oil ratio	Natural gas ratio
Regulation*post	−0.4752**	−0.4838***	0.4660***	0.0179
	(0.1926)	(0.1659)	(0.1604)	(0.0486)
Top-1000 enterprises program* Post	−0.0068	0.0106	−0.0037	−0.0070
	(0.0171)	(0.0088)	(0.0070)	(0.0064)
Ten major energy conservation projects*post	−0.0892***	0.0134***	−0.0057	−0.0078**
	(0.0090)	(0.0043)	(0.0041)	(0.0031)
Capital labor ratio	−0.1779***	−0.0350*	0.0065	0.0285**
	(0.0354)	(0.0196)	(0.0195)	(0.0135)
Debt capital Ratio	0.0338***	−0.0011	0.0016	−0.0005
	(0.0061)	(0.0020)	(0.0017)	(0.0015)
Employment	−0.0470***	0.0027	−0.0052**	0.0025*
	(0.0053)	(0.0025)	(0.0022)	(0.0014)
Firm age	0.0001	0.0001	−0.0001	0.0001
	(0.0001)	(0.0001)	(0.0001)	(0.0001)
Export	−0.0176***	−0.0016	−0.0006	0.0022
	(0.0050)	(0.0020)	(0.0015)	(0.0015)
Constant	0.7275***	0.9148***	0.0596***	0.0256**
	(0.0373)	(0.0160)	(0.0160)	(0.0104)
Year fixed effects	Y	Y	Y	Y
City fixed effects	Y	Y	Y	Y
Firm fixed effects	Y	Y	Y	Y
Industry fixed effects	Y	Y	Y	Y
Observations	277,028	202,115	202,115	202,115
R-squared	0.8764	0.9189	0.8764	0.8764

Notes: *** stands for $p < 0.01$, ** stands for $p < 0.05$, and * stands for $p < 0.1$. Robust standard errors are reported in parentheses. The two concurrent events, Top-1000 enterprises program and Ten major energy conservation projects, are controlled in regression model. Column (1) tests energy regulation's effect on energy intensity. Column (2)–(4) test energy regulation's effect on coal ratio, oil ratio and natural gas ratio separately.

pendent firms and low-energy dependent firms are reported in Column (3) and (4) of Table 7. The energy regulation conducted in the 11th FYP tends to be more effective on high-energy dependent firms.

7. Robustness checks

In this part, we do some robustness checks considering other concurrent events, using alternative measure of energy regulation and the model standard error compared to our basic model.

7.1. Concurrent events

If there exist any other events during the 11th FYP which may affect firm's energy intensity and energy structural, our estimates could be biased. To exclude the possibility and identify the effect of the energy regulation in the 11th FYP, we find Top-1000 enterprises program and ten major energy conservation projects during this period may influence our estimation results. The target of the Top-1000 enterprises program is that energy intensity should be greatly decreased. Energy consumption per unit of product reaches the advanced level in the domestic industry. And some enterprises reach the international advanced level or the industry leading level. Finally, this project should achieve energy saving of about 100 million tons of standard coal. The goal of the ten major energy conservation projects is to save 240 million tons of standard coal during the 11th FYP. Energy intensity of the key industries reaches or approaches the international advanced level at the beginning of 2010. We add the dummies of these two events with the iteration of *Post* in Eq. (1). And the regression results are shown in Table 8 which indicates that the energy regulation of the 11th FYP is still effective.

7.2. Alternative measure of energy regulation

Following the work of Chen et al. (2018) and Chen and Chen (2018), we select the frequency and proportion of energy-saving or energy related words in work reports of provincial governments as a proxy variable for regulation policy. The government work report is a programmatic document that guides governmental executive branches' work. Therefore, the frequency and proportion of energy-saving or energy related vocabulary in government work reports can more fully reflect the intensity of government's regulation. We re-estimate Eq. (1) using a measure of report ratio above in place of the 11th FYP used in the baseline specification. As shown in column (1) of Table 9, the coefficient of *report ratio* is negative and statistically significant, indicating that our afore mentioned results are not driven by the measure of energy regulation.

Table 9
Robustness checks.

Variables	(1)	(2)	(3)	(4)	(5)
	Energy intensity	Energy intensity	Coal ratio	Oil ratio	Natural gas ratio
Report ratio	−4.1245***				
	(1.5467)				
Regulation*post		−0.5038***	−0.4781***	0.4638***	0.0144
		(0.1812)	(0.1423)	(0.1206)	(0.0428)
Capital labor ratio	−0.1693***	−0.1650***	−0.0353**	0.0068	0.0286**
	(0.0372)	(0.0344)	(0.0153)	(0.0138)	(0.0123)
Debt capital ratio	0.0299***	0.0338***	−0.0011	0.0016	−0.0005
	(0.0067)	(0.0048)	(0.0016)	(0.0014)	(0.0012)
Employment	−0.0458***	−0.0450***	0.0026	−0.0051***	0.0026**
	(0.0053)	(0.0043)	(0.0016)	(0.0014)	(0.0010)
Firm age	0.0001	0.0000	0.0001	−0.0001	−0.0000
	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
Export	−0.0016	−0.0165***	−0.0017	−0.0006	0.0023*
	(0.0019)	(0.0051)	(0.0019)	(0.0016)	(0.0014)
Firm fixed effects	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes	Yes
City fixed effects	Yes	Yes	Yes	Yes	Yes
Observations	250,578	283,010	202,115	202,115	202,115
R-squared	0.8755	0.8753	0.9188	0.9103	0.8490

Notes: *** stands for $p < 0.01$, ** stands for $p < 0.05$, and * stands for $p < 0.1$. Robust standard errors are reported in parentheses. In column (1), we replace Regulation*Post with Report ratio to see if the results are consistent. In column (2), (3), (4) and (5), the results are based on two-way clustering of errors by firm and province-by-year. Data Source: the China Environmental Statistics Dataset for 2003–2009, the China Industry Business Performance Dataset for 2003–2009.

7.3. Alternative clustering methods

Some of our explanatory variables are grouped at province-year level and there may be time invariant unobserved factors affecting energy intensity at the province level, the standard error may be biased (Moulton, 1986). The results of Column (2)–(4) are based on two-way cluster of error by firm and province-by-year (Cameron, Gelbach, & Miller, 2011). This method allows for serial correlation on energy intensity and energy structure across firms as well as spatial correlation within each province-year. The estimators of our interest are still statistically significant.

8. Conclusions

Using a difference-in-differences method based on the 11th FYP in China, we estimate the effect of energy regulation on firms' energy intensity and energy structure change. The results indicate that tighter energy regulation leads to significant energy intensity decrease and firms switch their energy structure from using dirty fossil energy (i.e., coal) to a cleaner one (i.e., oil or natural gas). Additional estimation results show more quantitative evidence about the mechanism analysis of energy regulation's effect on energy intensity. First, energy regulation motivates firms' R&D inputs and results in technological innovation, which is a key factor cutting down energy intensity. So stricter energy regulation results in lower energy intensity. Second, under the implementation of energy regulation, energy share reallocation may exist between firms. Those high energy efficient firms will consume more fossil energy relative to the low energy efficient firms, which results in the decrease of firms' average energy intensity. Our findings also demonstrate that the decline of energy intensity is driven mainly by non-stated-owned firms. Because stated-owned firms have greater bargaining power over local governments and face more loosely energy regulation. We also prove that firms relying heavily on fossil energy may have been more likely to be regulated by local governments and their energy intensity reduces more.

This paper has been the first step toward understanding the effect of energy regulation on firms' energy intensity in developing countries. Much work remains to be done. Our sample covers a relatively short period of time due to data limitation, while firms might be able to better adjust their behavior in the long run. Further efforts should more precisely investigate the long-term effect of energy regulation with better data. Such analyses would be undoubtedly of great benefit in understanding how energy regulation works on energy intensity and energy structure.

Acknowledgements

Shiyi Chen thanks the supports from National Science Fund for Distinguished Young Scholars (71525006), Cheung Kong Scholars Programme and Shanghai Leading Talent Project. Dengke Chen thanks the supports from National Natural Science Foundation of China (71903033) and Theoretical Economics Class I Summit Plan of Fudan University.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.chieco.2019.101351.

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