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The effect of tax incentives on energy intensity: Evidence from China's VAT reform

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ABSTRACT

This paper examines the effect of how firms' energy intensity is affected by China's value-added tax reform, which provides permanent tax incentives for firms to invest in fixed assets. Using the difference-in-differences method, a unique firm-level data set is employed to examine the impact of VAT reform on firms' energy intensity. The results show that VAT reform significantly reduces firms' coal intensity by approximately 9%. There is a greater decrease in coal intensity for large-scale firms, firms in energy-intensive industries, and private firms after the reform. By encouraging firms to invest in fixed assets and improve output, this reform achieves an energy-saving effect. Our results shed new light on the effect of tax policy and can help inform the development of energy policies.

1. Introduction

China has experienced severe pressure to simultaneously reduce carbon emissions and ensure economic growth in recent years; therefore, improving energy efficiency is of vital importance. The traditional perspective is to adopt relevant policies to achieve specific goals. Economic policies are often used to stimulate economic growth, while energy policies are used to save energy. Actually, these economic policies usually have additional effects, as discussed in the following paragraphs on tax incentives, which also have a significant influence on firms' energy efficiency.

Improving the efficiency of fossil energy use is still very important. It is hard to satisfy the energy demand in areas with high energy consumption using only renewables, due to the limitations of new energy resources, such as the instability of wind and solar power generation and energy loss in long-distance transmission (Cavallo, 2007). According to the International Energy Agency, renewables provided only 13.9% of the world's total primary energy supply in 2017, while fossil fuels provided 86.1% (Halkos and Gkampoura, 2020).

Environmental policies could achieve energy-saving effects to some extent, but from an overall national perspective, the effect of regional environmental regulations tends to be overestimated. Because of the pollution haven effect, regional environmental regulations are likely to cause pollution transfer from highly regulated regions to less regulated regions (Chung, 2014; Di, 2007). Furthermore, the energy-saving effect of resource taxes is unsatisfactory. Resource taxes were originally designed to increase the energy price and consequently improve energy efficiency (Xu et al., 2015). In China, however, the resource tax rate is too low to significantly increase the energy price and thus improve energy efficiency (Zhang et al., 2013). Moreover, the revenue from resource taxes is collected by local governments, the resource tax comprises even over 10% of total revenue in some regions,[1] which becomes an incentive for exploitation, the tax may act as a kind of resource curse.

Similarly to most governments in developing countries, the Chinese government experiences a trade-off between energy savings and economic growth. In most situations, the Chinese government emphasizes economic growth. Yao and Chang (2015) prove that China's energy policies are not originally intended to improve energy security, but are

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[1] In Shanxi Province, for example, resource tax accounted for 13.55% of total tax revenue in 2015.

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passive reactions to macroeconomic reform. In addition, some government subsidies weakened the effect of pollution charges on environmental preservation in China's reformed economy (Fisher-Vanden and Ho, 2007).

Tax incentives are widely used to stimulate investment and economic growth (Hall and Jorgenson, 1967; Hassett and Hubbard, 2002), especially during economic recessions (Hicks and LaFaive, 2011). In 2004, the Chinese government reformed its production-based value-added tax (VAT) system into a consumption-based VAT system to stimulate the economy in certain industries located in three northeastern provinces. Firms can deduct their costs of purchasing capital goods when calculating their tax base (Liu and Mao, 2019). In 2007, the pilot VAT system was expanded to 26 cities and certain industries in central China. At the beginning of 2009, it was adopted nationwide. The new VAT system subsequently had a great influence on the development of factories in China. The reform reduces firms' capital costs[2] and stimulates their investment in fixed assets, which should accelerate their technological progress and improve productivity (Liu and Lu, 2015; Zhang et al., 2018).

While studies show that VAT reform has a positive effect on firms' investment and productivity(Liu and Mao, 2019; Wang, 2013; Zhang et al., 2018), it is still unknown whether VAT reform improves firms' energy efficiency. In this paper, we examine the effect of the VAT reform on firms' energy intensity and its underlying mechanism. Using a comprehensive and unique firm-level data set including energy consumption data, we employ a difference-in-differences (DID) approach to exploit the quasi-experimental setting created by the VAT reform. Our results show that the VAT reform can significantly reduce firms' coal and total energy intensity. In particular, large-scale firms, firms in energy-intensive industries, and private firms show a greater decrease in coal intensity after the reform. These firms are more capable of purchasing new equipment. Thus, the VAT reform achieves an energy-saving effect by influencing firms' investments in fixed assets.

Our contributions focus on three aspects. First, previous studies mainly focus on the effect of energy policies on energy savings (Kalkuhl et al., 2013; Xu et al., 2015; Zhu et al., 2018), while few investigate the effect of economic policies on energy savings. Unlike traditional studies, we introduce a novel perspective regarding the VAT reform: while the reform aims to promote economic growth, it also has an unintended effect on firms' energy efficiency. Therefore, our study complements the literature by focusing on the impact of economic reform rather than energy policies on firms' energy efficiency. In addition, unlike energy policies or tax incentives that target a relatively narrow scope of firms, such as energy-intensive firms or firms in renewable energy industries (Cao and Karplus, 2014), the VAT reform is likely to have a broader effect on firms' energy intensity because its incentives are provided to both renewable energy firms and traditional firms that rely on fossil energy.

Second, although some studies examine the effect of the VAT reform, they all focus on how it stimulates economic growth, such as productivity and investments in fixed assets (Liu and Mao, 2019; Wang, 2013; Zhang et al., 2018). In contrast, our study shows that in addition to firms' output, the VAT reform promotes firms' energy efficiency. Therefore, a comprehensive evaluation of economic reform or policy changes should consider not only their effect on firms' output but also their relative influence, such as energy efficiency.

Third, we use a representative data set and a scientific model to study the impact of tax incentives on energy intensity, and derive more convincing and robust empirical evidence. In addition, we exploit all variations of the VAT reform implemented at the regional and industrial levels in our model. The firm-level data have some advantages over region-level data because they capture the heterogeneous effect of VAT reform policies within sectors (Fisher-Vanden et al., 2004). Some studies examine firm-level energy efficiency, but only include certain industries or regions (Li, 2011) or focus only on large firms (Zhu et al., 2018), which may lead to selection bias. Other studies use data on energy consumption costs[3] (Boyd and Curtis, 2014), but these data are not suitable to measure energy intensity. We use a more comprehensive data set, which includes energy consumption information on firms with various types of ownership, sizes, and industries in all Chinese regions; therefore, we alleviate the issue of sample selection bias and conduct a heterogeneous analysis on the effect of VAT reform.

The rest of our paper is organized as follows. Section 2 introduces the tax reform in detail and the related policy background. Section 3 describes the econometric model and the data sources. Section 4 reports our empirical results, which include benchmark regressions and heterogeneous analyses. Section 5 further discusses the effect on total energy, robustness checks, and mechanism analysis. Finally, Section 6 concludes.

2. China's VAT reform

VAT is widely adopted worldwide, including in China, because of its low administration costs and relatively minor economic distortion. VAT is levied when value is added at various stages of production or distribution from the purchase of raw materials to the final products sold to retail consumers. VAT is calculated using the following equation, where the difference between output and input values constitutes the tax base. Capital goods purchases in a traditional consumption-based tax system are regarded as an input value, which is deductible when calculating tax bases.

$$\text{VAT to be paid to the government} = (\text{Output value–Input value}) \times \text{Tax rate}$$

In 1994, a VAT system was introduced nationwide in China. By 2003, VAT accounted for 36.15% of China's total tax income. However, this regime did not allow the deduction of capital goods purchases from the tax bases, i.e., the VAT system was production-based. During this early period, the implementation of a production-based VAT system was arguably a reasonable attempt to avoid overinvestment in China's overheating economy and eliminate tax evasion. However, the Chinese VAT system resulted in the double taxation of products in circulation: i.e., producers paid the first tax for their final products, while users paid the second tax as intermediate inputs. Moreover, in the long run, China's production-based VAT system discouraged firms from investing in capital goods and updating equipment because of the high cost of capital goods.

In response to these drawbacks, China gradually began to promote VAT reform. In 2004, China introduced a new VAT system in some northeast regions to target equipment manufacturing, petrochemical, metallurgy, shipbuilding, automobile manufacturing, and agricultural product processing industries. In 2007, 26 central cities that were established industrial bases experimented with VAT reform. In addition to the abovementioned industries, the VAT reform was expanded to the electricity and extractive industries. On July 1, 2008, the VAT reform expanded to five eastern Inner Mongolian cities, affecting the same industries as mentioned above. In the same year, to support reconstruction work in Wenchuan's earthquake-stricken areas, the Sichuan, Shanxi, and Gansu provinces also adopted the VAT reform. By January 1, 2009, all of China was included in the VAT reform, which now impacts all

[2] Liu and Mao (2019) show that the tax component for firms' capital costs was $1/(1–0.17) \approx 1.2$ before the VAT reform and $(1–0.17)/(1–0.17) = 1$ afterwards, where 0.17 is the general VAT rate in China. Therefore, the VAT reform reduces firms' capital costs and subsequently their tax base. This increases firms' cash flow and reduces their reliance on external financing access, which subsequently reduces their capital costs.

[3] The data are from the World Bank data set and the World Management Survey.

industries.

The VAT reform has a considerable influence on firms; it increases their productivity (Liu and Mao, 2019) and provides tax incentives to increase their investments in fixed assets (Wang, 2013; Zhang et al., 2018). More importantly, the VAT reform encourages firms to invest in production machinery rather than in new factories and buildings (Wang, 2013). However, it remains uncertain whether the reform improves firms' energy efficiency. In the following sections, we conduct detailed empirical tests to answer this question.

3. Econometric model and data

3.1. Difference-in-differences method

The VAT reform was implemented gradually across different regions and different industries; this provides us with an ideal setting to use a staggered DID method to examine how tax incentives affect firms' energy intensity. The DID method can help eliminate some endogeneity problems caused by omitted control variables and reverse causality.[4] In particular, we run the following double fixed effect model:

$$energyint_{it} = \alpha + \beta \times reform_{it} + \gamma \times X_{it} + firm_i + year_t + \mu_{it} \quad (1)$$

where $energyint_{it}$ is the energy intensity of firm i in year t, which is calculated by the following formula:

$$energyint_{it} = \frac{energy\ consumption_{it}}{output_{it}},$$

where $output_{it}$ is the total output value of firm i in year t and the nominal values of total output are deflated using provincial price indices from the National Bureau of Statistics of China (NBS). $energy\ consumption_{it}$ is the energy consumed to produce the output of firm i in year t.

The key explanatory variable, $reform_{it}$, is set to 1 if firm i was affected by the VAT reform in year t. Otherwise, this variable is set to 0. We are mainly interested in parameter β of Model (1). According to the argument in Sections 1 and 2, we expect to have a significant negative parameter estimation for $reform_{it}$.

The control variables, X_{it}, in the model include firm size, firm age, firm return on assets (ROA), and city GDP per capita.

Firm size is denoted by *assets*. Firm size affects productivity because of the existing economies of scale (Christensen and Greene, 1976), including in energy-intensive industries (Cole et al., 2006; Du et al., 2013). In general, the larger a firm is, the better it can support research and development into energy-saving and emission-reduction technologies (Dai et al., 2018; Kafouros et al., 2015). The total assets of firms reflect their production scale (Du et al., 2013; Liu and Mao, 2019; Lougee and Marquardt, 2004); thus, we use total assets to measure the firm size and take its logarithm to adjust the skewness of the variable. We predict a negative relationship between firm size and energy intensity due to economies of scale.

Firm age is denoted by *age*, which has two potential effects on their energy intensity. The first effect is negative because older firms are more capable of acquiring advanced (i.e., energy-efficient) technologies than younger firms or because of the learning-by-doing effect (Du et al., 2013; Sahu and Narayanan, 2011). The second effect is positive because energy-intensive production equipment is hard to replace, and older firms may tend to use obsolete equipment with low efficiency. We use the sample year minus the year of firm establishment to measure firm age and also take its logarithm.

Firm ROA is denoted by *roa*. It is uncertain whether the relationship between firms' energy intensity and ROA is positive or negative. On the one hand, firms with higher ROA usually have greater production capability than firms with lower ROA; therefore, they may have lower energy intensity. On the other hand, firms may choose to increase their ROA at the cost of high energy consumption. We use the firms' profit divided by the firm owners' equity to measure firm ROA.

The GDP per capita at the city level (denoted by *gdpper*) is used to measure the level of economic development. We deflate the GDP per capita according to the provincial price indices from the NBS. Developed regions generally have better external environments for efficient production, firms in these regions are more likely to benefit from agglomeration effects than firms in undeveloped regions (Yu, 2012). We control the GDP per capita for the cities where firms are located.

We also control firm fixed effects ($firm_i$) and year fixed effects ($year_t$) in the staggered DID model (formula (1)). The year fixed effect is used to control for nationwide shocks and trends that influence all firms over time, such as business cycles and national changes in regulations and laws. The firm fixed effect is used to control for time-invariant, unobserved firms' characteristics that shape their energy efficiency. We do not need to include the $time_{it}$ and $treat_{it}$ dummy variables in the staggered DID model as in the basic DID model,[5] because we control for time and firm fixed effects, and the $time_t$ and $treat_i$ dummy variables will be absorbed by the fixed effects in the staggered DID model.

3.2. Data source and description

We obtain data from 2007 to 2011 for the firms' energy consumption from the National Tax Survey Database (NTSD), which is collected by the State Administration of Taxation of China and the Ministry of Finance of China. Using the stratified random sampling method, the firms under investigation provide the tax authorities with data concerning taxation, finance, and operations, which constitute the basic information for evaluating the impacts of tax policies (Liu and Mao, 2019).

Our sample includes the mining, manufacturing, electricity production and supply, heat, gas, and water, and construction industries. Table A1 provides detailed information about these industries. The NTSD includes all industries in the national economy, but firms in other industries provide no energy consumption data. In addition, we use only the data for manufacturing industries to identify the robustness of the policy effect.

The data from manufacturing industries are processed as follows. First, duplicate observations are removed according to the taxpayer identification number and business name. Second, we drop the observations with missing variables. In addition, we drop outliers according to the following criteria: (1) observations with negative fixed assets; (2) firms with outputs beyond the range (0.1–0.99); (3) firms with an S or T industry code[6] or firms in the tertiary sector with industry codes <5 digits; and (4) firms with increasing or decreasing coal intensity by a magnitude of 1000 times relative to that in the previous year.[7] We unify the industry codes based on GB/T 4754–2011 of the national economy industry classification in 2011 according to the industry name in the

[4] China's VAT reform was initiated at the regional and industrial level, which causes an exogenous shock to firms' energy efficiency. That is, the VAT reform may influence firms, but firms cannot likewise influence this reform. In addition, the DID estimation technique compares changes instead of levels between the treatment and control groups, which can eliminate the fixed difference between groups that would otherwise cause an omitted variables bias.

[5] The basic DID model is as follows: $energyint_{it} = \alpha_0 + \beta_1 time_t + \beta_2 treat_i + \beta_3 time_t \times treat_i + X_{it} \times \gamma + \mu_{it}$, where i denotes the firm and t denotes the year. $time_t$ is the dummy variable for the reform year and $treat_i$ is the dummy variable representing reform firms.

[6] S represents the public administration, social security, and social organization industry, while T represents international organizations.

[7] Firms' output is counted in thousands of yuan in RMB, while their energy consumption is counted in tons. Therefore, it is likely that the survey respondents may mistake the unit of output as yuan in RMB or mistake the unit of energy consumption as kg. We eliminate this kind of mistake.

data set. Finally, we obtain 174,483 observations and winsorize all the continuous variables at the 0.1% and 99.9% levels to eliminate the influence of outliers.

We mainly focus on firms' coal intensity because coal consumption accounts for approximately 70% of the total energy consumption during our study period according to the NBS. In addition, the coal cap is more costly than a cap on all fossil fuels (Karplus et al., 2016). In Section 5.1, we also analyze the policy effect on total energy intensity.

Firms' coal intensity ranges from 0.0001 to 7.88 tons/thousand yuan (Table 1) with an average of 0.171 tons/thousand yuan and standard deviation (SD) of 0.571 tons/thousand yuan, which indicates a high level of heterogeneity within the sample. To adjust the skewness of variables, we take the logarithm of cities' GDP per capita, firm assets, and firm age. The summary statistics for all variables are within reasonable ranges.

4. Empirical results

4.1. Benchmark analysis

Our benchmark analysis explores the effect of the VAT reform using firm-level coal intensity as the dependent variable. We start the estimation by controlling for firm and year fixed effects in Column (1) of Table 2. The results show that the coefficient of the reform item, *reform*, is significantly negative, which confirms that the VAT reform reduces firms' coal intensity. In Columns (2) and (3), we further add additional control variables. In Column (4), we retain only the manufacturing industry.

The main results of our benchmark analysis are as follows. First, the VAT reform can significantly decrease firms' coal intensity: the average treatment effect of the reform is approximately −0.0162 tons/thousand yuan as shown in Column (3), which is statistically significant at the 1% level. The economic significance is also remarkable, on average, the reform reduces the coal intensity by approximately 9% compared with the average 0.171 tons/thousand yuan (Table 1). Second, we observe significant economies of scale, our results show that relatively large-scale firms exhibit better energy efficiency than smaller firms, which is consistent with Karplus et al., 2018. Third, firms' ROA has a significantly negative effect on firms' coal intensity, which means that firms with higher profitability have lower coal intensity. Fourth, the results of manufacturing industry samples are still significant: the VAT reform reduces firms' coal intensity by approximately 10% compared with an average 0.1244 tons/thousand yuan for manufacturing firms.

We also perform a sensitivity test because according to the Tax Bulletin from the State Taxation Administration,[8] in some regions, the VAT reform regulations are put forward in July. In the benchmark regression, if the regulations are put forward in July, we define the implementation year of the reform as the initial treatment year for the firms. In our sensitivity test, we treat the next implementation year as the initial treatment year and define the treated variables as "*reform-new*."[9] The results are still significant (see Table A2).

4.2. Heterogeneous effect analysis

We further explore the heterogeneous effects of VAT reform on different kinds of firms. In this section, we analyze the different policy effects on firms of different sizes, and firms in different energy-intensive industries. In addition, we distinguish different types of firms according to their ownership and analyze the heterogeneous effects on different types of firms.

In our first heterogeneous analysis, we examine the different responses of firms of different sizes to the VAT reform. To perform this analysis, we run the following model:

$$coalint_{it} = \alpha_0 + \beta_1 reform_{it} + \beta_2 lnasset_{it} + \beta_3\, reform_{it} \times lnasset_{it} + X_{it}\gamma + firm_i + year_t + \mu_{it} \quad (2)$$

where $lnasset_{it}$ is the firm size as measured by firm i's total assets for the year t. All other variables are defined as in Model (1). We are interested in the coefficient of the interaction between firm size and the reform variable ($reform_{it} \times lnasset_{it}$), β_3, which we expect to be significantly negative.

In our second heterogeneity analysis, we consider the responses of firms in different kinds of industries, namely, industries with different energy intensity levels. To perform this analysis, we run the following model:

$$coalint_{it} = \alpha_0 + \beta_1 reform_{it} + \beta_2 intensity_{it} + \beta_3 reform_{it} \times intensity_{it} + X_{it}\gamma + firm_i + year_t + \mu_{it} \quad (3)$$

where $intensity_{it}$ is calculated as the energy intensity of the two-digit industries based on the *China Energy Statistical Yearbook* (CESY); the unit is tons/thousand yuan.

Because of the different scales of the variables, we normalize the interaction variables *lnasset* and *intensity*, which are demeaned and scaled by the standard deviation to make the coefficients interpretable. All other variables are defined as in Model (1). We are interested in the coefficient of the interaction between firm intensity and the reform variable ($reform_{it} \times intensity_{it}$), β_3, which we expect to be significantly negative.

The results are shown in Table 3. Columns (1) and (2) show the results of the DID model with the interaction between firm size and the reform variable, and Column (2) shows the results with control variables. Columns (3) and (4) show the results of the regressions with the interaction between two-digit industries' coal intensity and reform variable, and Column (4) shows the results with control variables.

As shown in Table 3, the effect of VAT reform on energy efficiency is strengthened for large-scale firms and firms in energy-intensive industries. Compared with our benchmark results, the coefficient of

[8] The *Tax Bulletins* for 2003–2021 from the Chinese State Taxation Administration are available at the following URL: http://www.chinatax.gov.cn/chinatax/n810341/n810765/index.html.

[9] The regulations include No. 62 (July 2007), No. 75 (July 2007), No. 94 (July 2008), and No. 108 (July 2008).

Table 1
Description of the variables.

Variables		Mean	SD	Min	P25	P50	P75	Max
Energy intensity (tons/thousand yuan)	*coalint*	0.171	0.571	0.0001	0.0028	0.016	0.0724	7.880
GDP per capita (yuan)	*lngdppc*	10.390	0.627	8.549	9.923	10.380	10.930	11.710
Total assets (thousand yuan)	*lnasset*	10.450	1.897	5.268	9.140	10.350	11.660	17.110
Age (year)	*lnage*	2.024	0.690	0.000	1.609	2.079	2.485	4.007
ROA (ratio)	*roa*	0.0163	0.108	−1.064	−0.009	0.00760	0.0393	1.047

Table 2
Firms' responses to the VAT reform: Baseline results.

Variables	(All industries)	(All industries)	(All industries)	(Manufacturing-only)
	coalint	*coalint*	*coalint*	*coalint*
reform	−0.0157***	−0.0159***	−0.0162***	−0.0125**
	(0.006)	(0.006)	(0.006)	(0.006)
lngdppc		−0.0067	−0.0065	0.0062
		(0.020)	(0.020)	(0.019)
lnasset		0.0299	−0.0083*	−0.0031
		(0.024)	(0.005)	(0.005)
lnasset^2		−0.0019		
		(0.001)		
lnage		−0.0017	−0.0014	−0.0020
		(0.006)	(0.006)	(0.006)
roa		−0.0908***	−0.0899***	−0.0967***
		(0.019)	(0.019)	(0.022)
Observations	174,483	174,483	174,483	155,995
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
R-squared	0.620	0.620	0.620	0.511

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

Table 3
Heterogeneous effect analysis for firms at different scales and in different industries.

Variables	(Different scales)	(Different scales)	(Different energy intensity industries)	(Different energy intensity industries)
	coalint	*coalint*	*coalint*	*coalint*
reform	−0.0152***	−0.0158***	−0.0129**	−0.0130**
	(0.006)	(0.006)	(0.006)	(0.006)
reform×*lnasset*	−0.0088**	−0.0089**		
	(0.004)	(0.004)		
reform×*intensity*			−0.0477***	−0.0478***
			(0.006)	(0.006)
Control variables	No	Yes	No	Yes
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	174,483	174,483	174,483	174,483
R-squared	0.620	0.620	0.621	0.621

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

reform×*lnasset* in Column (2) is −0.0158, which implies that the average effect of the VAT reform on energy intensity is strengthened by 9.24% with a one standard deviation increase in firm size. Large-scale firms face relatively small financing constraints and have stronger ability to purchase equipment (Liu and Mao, 2019). Similarly, the coefficient of *reform*×*intensity* in Column (4) is −0.0478, which implies that the average effect of the VAT reform is strengthened by 27.95% with a one standard deviation increase in energy intensity. Most energy-intensive industries are capital-intensive, and VAT reform reduces capital costs; therefore, the effect is more significant for these industries.

Table 4
Heterogeneous effect analysis for firms with different types of ownership.

Variables	(State-owned enterprises)	(Foreign-owned enterprises)	(Privately owned enterprises)
	coalint	*coalint*	*coalint*
reform	−0.0445	−0.0178	−0.0223**
	(0.041)	(0.017)	(0.009)
lngdppc	0.0744	−0.0779*	0.0197
	(0.147)	(0.045)	(0.032)
lnasset	−0.0669**	−0.0008	−0.0207**
	(0.034)	(0.013)	(0.008)
lnage	−0.0255	−0.0028	−0.0093
	(0.020)	(0.020)	(0.010)
roa	−0.0931	−0.0529	−0.0820***
	(0.069)	(0.032)	(0.030)
Firm FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Observations	5692	26,238	52,457
R-squared	0.732	0.625	0.592

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

Next, we analyze the heterogeneous effect of the VAT reform on firms with different kinds of ownership: state-owned, foreign-owned, and privately owned firms.[10] We conduct Model (1) for three subsamples to explore this issue. Columns (1–3) in Table 4 show the regression results for the subsamples of state-owned, foreign-owned, and privately owned firms, respectively.

The results in Table 4 show that the VAT reform policy has a significant effect on privately owned firms, which have more operating flexibility. These results are consistent with the findings of Gao et al. (2013), Poncet et al. (2010), and Li et al. (2008). Moreover, VAT reform could reduce or remove the financing constraints during the firms' investment. Non-state-owned firms face severe financing constraints, therefore, they are more sensitive to the VAT reform, which is consistent with Liu and Mao (2019).

5. Further analysis

5.1. Effect on total energy

We observe the policy effect of VAT reform on total energy intensity by collapsing the data for the electricity and different kinds of coal and oil into standard coal, which is then denoted as total energy. Specifically, according to the CESY, we refer to the consumption data for different kinds of coal (e.g., raw, cleaned, other washed coal, coke, etc.) and oil (e.g., gasoline, diesel, kerosene, etc.) from different industries. Thus, firms in different two-digit industries are weighted to calculate

[10] According to the provisions on the classification of firm registration types issued by the NBS and the State Administration of Industry and Commerce, we classify "foreign capital, Hong Kong, Macao, and Taiwan capital (foreign), state-owned (state), private, and others" using the firm registration type and code as shown in the data set.

Table 5
Total energy intensity analysis.

Variables	(All industries)	(Excluding industries that are heavy consumers of gas)	(Industries that mostly consume fossil energy)
	Total energyint	*Total energyint*	*Fossil energyint*
reform	−0.1781*	−0.2042**	−0.0313***
	(0.106)	(0.095)	(0.008)
lngdppc	−1.1902***	−0.8940***	−0.0011
	(0.336)	(0.295)	(0.029)
lnscale	0.1417**	0.1325**	−0.0150**
	(0.066)	(0.059)	(0.007)
lnage	−0.0335	−0.0266	−0.0079
	(0.087)	(0.079)	(0.007)
roa	−0.3539	−0.3123	−0.0998***
	(0.235)	(0.219)	(0.023)
Observations	174,483	154,736	70,044
Firm FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
R-squared	0.421	0.433	0.648

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

their total consumption of standard coal. We calculate firms' total energy intensity based on the following formula[11]:

$$total\ energyint_{it} = coalsta_s \times coalint_{it} + oilsta_s \times oilint_{it} + elecsta_s \times elecint_{it},$$

where s denotes the two-digit industry of firm i; $coalsta_s$ is the industry coefficient calculated according to the two-digit industry data from the CESY, which is calculated by $coalsta_s = \sum_k \frac{coal_{ks}}{coal_s} \times standard_k$, where k denotes different kinds of coal, $coal_{ks}$ means the $coal_k$ consumed by industry s, $coal_s$ is the total coal consumption by industry s, and $standard_k$ means the conversion coefficient to standard coal of $coal_k$; and $oilsta_s$ is calculated similarly. According to the CESY, the converted coefficient of electricity is uniform across industries.[12] By using this weighting coefficient, we obtain a more accurate measure of firms' total energy consumption. Moreover, we sum coal and oil as fossil energy and calculate its intensity based on the following formula:

$$fossil\ energyint_{it} = coalsta_s \times coalint_{it} + oilsta_s \times oilint_{it}.$$

Column (1) of Table 5 shows the results for all sampled industries, while Column (2) shows the results for the sample excluding industries that are heavy consumers of gas,[13] excluding these latter industries relieves the impact of the absence of data for gas consumption in the NTSD. Column (3) shows the impact on firms' fossil energy intensity in industries where coal and oil are the most significant sources. Specifically, we calculate the proportion of coal and oil consumption in the total energy consumption at the industry level according to the NBS's data set and choose the top third of the industries for our analysis.[14]

Our results show that the VAT reform policy has a significant effect on firms' total energy intensity. The estimated coefficient in Column (1) of Table 5 shows that the total energy intensity decreases by approximately 31% compared with the average value of 0.5762 tons of standard coal per thousand yuan.[15] The coefficient in Column (2) is still significantly negative and similar to Column (1), which shows that our results are robust. We further test the results for industries that mostly consume fossil energy (i.e., coal and oil) in Column (3). The coefficient for the VAT reform policy is −0.0313, which represents an approximately 13% decrease in firms' total fossil energy intensity compared with an average of 0.2376. Together, these results confirm that the VAT reform improves firms' total energy efficiency significantly.

5.2. Robustness test

5.2.1. Test of the parallel trend assumption

The validity of our main results (see Table 2) relies on the assumption that there are no differences in trends between the treated and control firms during the pretreatment period (Beck et al., 2010; Nunn and Qian, 2011). Hence, the difference between the treatment and control groups should be constant over time. If the two groups show significant differences before the implementation of the VAT reform policy, our results could be caused by time trends instead of the VAT reform. To rule out this concern, we employ an event study method and regress our dependent variable, energy intensity, on a vector of year dummies by indicating the years relative to the VAT reform. For example, D^{-j} indicates the j-th year prior to the reform, while D^j indicates the j-th year after the reform. D^{-2} indicates two years or earlier before the reform, while D^3 indicates at least three years after the reform. We exclude the reform year D^0 to avoid any multicollinearity problems, which may make the model inestimable. The model is as follows:

$$coalint_{it} = \alpha_i + \beta_{-2}D_{it}^{-2} + \beta_{-1}D_{it}^{-1} + \beta_1 D_{it}^1 + \beta_2 D_{it}^2 + \beta_3 D_{it}^3 + firm_i + X_{it} \times \gamma + year_t + \mu_{it} \quad (4)$$

Fig. 1 presents the estimated coefficients for the year dummies with 95% confidence intervals. We can conclude that the trends for the treated and control firms are not significantly different in the pretreatment period, which satisfies the parallel trend assumption. The point estimates show that before the reform, the coefficients are approximately 0; therefore, the trend does not differ significantly between the treatment and control groups. After the VAT reform, we observe a significant decrease in the trend of firms' coal intensity. This result implies that the VAT reform decreases treatment firms' coal intensity significantly.

5.2.2. Other contemporaneous shocks

Other policies may also influence our results. Therefore, we consider the potential influence of other policies to further validate our results. Specifically, we consider policies that are aimed at saving energy and

[11] No gas consumption data are available in the NTSD data set; therefore, we do not include gas in the calculation formula.

[12] According to the CESY, the heat value of 1 kW-hour electricity is equivalent to that of 0.1229 kg of standard coal. As electricity is measured in 10,000 kW-hours in the data set, we convert firms' electricity consumption into the equivalent consumption of standard coal by multiplying the conversion factor by an appropriate 1.229.

[13] Specifically, we exclude industries that consume gas for >10% of their total energy. These are the top three in our data set, namely, the two-digit industry codes B07, C26, and D45. We use the NBS data set to identify these industries.

[14] Specifically, they include the following two-digit industry codes: C25, D44, B06, D45, C31, C15, C22, C32, C14, B10, C13, C27, C16, and C20.

[15] The policy effect is larger than the benchmark regression because it includes the effect on different kinds of energy (i.e., it is the summed effect of the three energy sources: coal, oil, and electricity).

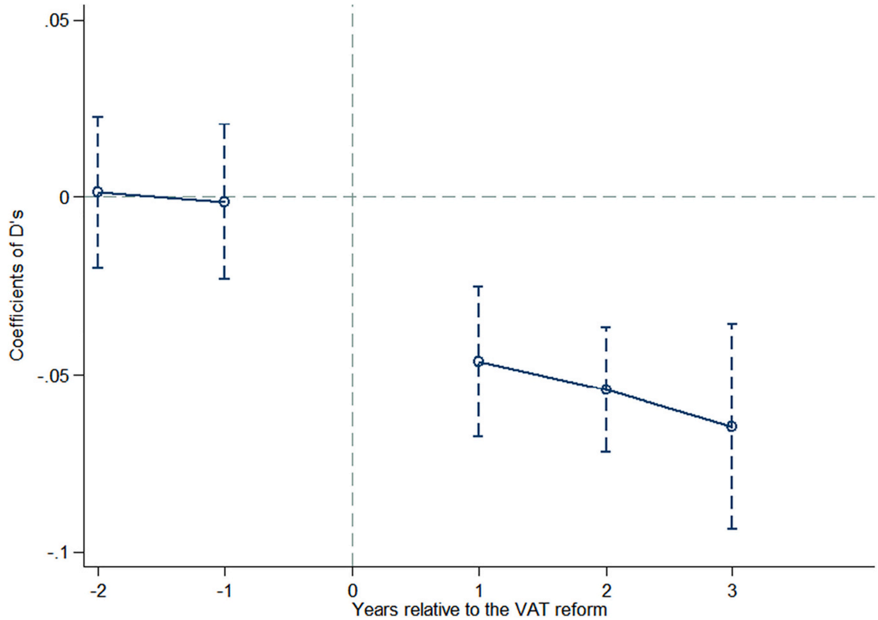

Fig. 1. The dynamic effect of the VAT reform.

Table 6
Top 1000 energy-consuming enterprises program shock.

Variables	(Delate Top-1000 firms listed in program)	(Delate Top-1000 firms listed in program)	(Delate Top-1000 firms listed in data set)	(Delate Top-1000 firms listed in data set)
	coalint	*coalint*	*coalint*	*coalint*
reform	−0.0153***	−0.0161***	−0.0123**	−0.0123**
	(0.006)	(0.006)	(0.005)	(0.005)
Control variables	No	Yes	No	Yes
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	173,255	173,255	168,843	168,843
R-squared	0.620	0.621	0.591	0.591

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

decreasing pollution.

First, we attempt to rule out the effect of an important energy-saving policy launched by the National Development and Reform Commission in 2006, named the Top 1000 Enterprise Energy Saving Program (Zhu et al., 2018). This program aimed to reduce energy consumption per unit of GDP by 20% between 2005 and 2010 and included a total of 1008 firms that consumed a large amount of energy.

We remove the firms listed in the Top 1000 Enterprise Energy Saving Program in our sample and replicate the benchmark regression. Columns (1) and (2) of Table 6 show our significant results.[16] To check the robustness of these results, we delete the top 1000 energy-consuming firms in our sample for 2007 and 2008 (before the nationwide reform). Columns (3) and (4) present the results after deleting these firms and the coefficients are still significant. In conclusion, our results concerning the effect of the VAT reform on firms' energy efficiency remain robust when considering the potential effect of the Top 1000 Energy-Consuming Enterprises Program.

Second, we consider an important pollution-decreasing policy that could also potentially drive our empirical findings. In both the 10th and 11th Five-Year Plan periods (2001–2005 and 2006–2010), the Chinese central government established a national goal to reduce sulfur dioxide (SO_2) emissions by 10%. Earlier policies were unsuccessful in reducing SO_2 emissions, which increased by 28% during the 10th Five-Year Plan. In May 2007, the State Council responded to this increase by issuing the Comprehensive Work Plan for Energy Conservation and Emission

Table 7
Reform of SO_2 emission charges shock.

Variables	(1)	(2)
	coalint	*coalint*
reform	−0.0156***	−0.0161***
	(0.006)	(0.006)
so_2	−0.0034	−0.0033
	(0.005)	(0.005)
Control variables	No	Yes
Firm FE	Yes	Yes
Year FE	Yes	Yes
Observations	174,483	174,483
R-squared	0.620	0.620

Robust standard errors in parentheses.
*** $p < 0.01$.

Table 8
Mechanism analysis.

Variables	(1)	(2)	(3)
	lnoutput	*lnfixassetadd*	*lninventory*
reform	0.0216*	0.0900***	−0.0040
	(0.012)	(0.030)	(0.009)
Control variables	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Observations	174,483	90,773	145,379
R-squared	0.916	0.785	0.963

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

[16] We are able to merge 1228 observations from the Top 1000 Energy-Consuming Enterprises Program list with our data set, because the NTSD data set is stratified by random sampling and unbalanced data, which means that some enterprises are not observed in certain years from 2007 to 2011.

Reduction, which raised the charges for SO_2 emissions step by step from 2007 to 2014. During this period, most provinces raised their charges for SO_2 emissions from 0.63 yuan per kg of SO_2 to 1.26 yuan per kg of SO_2 (see Table A3).

We simultaneously control the variable for the reform of SO_2 emission charges. The variable SO_2 in Table 7 is defined as a dummy that equals 1 if the firm is incorporated in a province that has raised the SO_2 emission charge and equals 0 otherwise. The coefficients for the VAT reform are still significant (see Table 7), which shows that our results remain robust. The coefficients for the reform of SO_2 emission charges are not significant, possibly because the reform effect only reduced emissions and encouraged firms to spend more money on pollution control rather than improving their energy efficiency.

5.3. Mechanism analysis

The above empirical results indicate that the VAT reform has a negative effect on firms' energy intensity. Next, we analyze its mechanism. We consider two mechanisms: i.e., the VAT reform increases (i) firms' output and (ii) firms' investment in fixed assets (see Table 8 for the results).

First, because energy intensity measures the energy consumption per unit of output, the increase in firms' output is likely to contribute to the decrease in firms' energy intensity. Column (1) in Table 8 shows that the VAT reform increases firms' output, which is consistent with Liu and Mao (2019). To confirm whether selection bias exists, we test the parallel trend assumption (the method is shown in Fig. 1), as shown in Fig. A1. The results show that there is no significant selection bias; that is, the VAT reform samples are random.

Second, the VAT reform provides firms with tax incentives to invest in fixed assets to update their production equipment and technology, which contributes to firms' energy efficiency improvement. Therefore, we test the effect of the VAT reform on investment in fixed assets. In addition, considering that large investments in equipment need time to plan and execute, the VAT reform shows a lagged effect. We redefine the VAT reform dummy (if the reform is in July, we treat it as prereform and the following year as postreform). Column (2) in Table 8 shows the results of our analysis, which indicate that the reform significantly increases firms' investment in fixed assets. These results are consistent with Liu and Mao (2019) and Zhang et al. (2018). Hence, the VAT reform improves both firms' output and investments, which fundamentally improves their energy efficiency. From this perspective, VAT reform is able to address energy-saving problems and stimulate output simultaneously.[17]

Finally, to test the robustness of the mechanism further, we analyze the influence of the VAT reform on firms' inventory as a placebo test. The VAT reform influences firms' ability to update their production equipment by allowing them to deduct the cost of purchasing capital goods when calculating the VAT bases. Therefore, the VAT reform mainly affects firms' ability to purchase fixed assets rather than liquid assets. We conduct an additional examination using firms' inventory as the independent variable, which is measured by the firms' average liquid assets at the beginning and end of the year. As shown in Column (3) of Table 8, the effect of the VAT reform on investment in liquid assets is not significant. Therefore, the VAT reform does not influence firms' ability to purchase liquid assets, which proves the robustness of our results regarding the mechanism.

6. Conclusion

By allowing firms to deduct the cost of purchasing capital goods when calculating their VAT bases, China's VAT reform provides tax incentives that encourage firms to update their production equipment and improve their energy efficiency. Using a comprehensive firm-level data set including energy consumption data, we apply the staggered DID approach to the VAT reform in China and test its effect on firms' energy intensity. Our empirical findings show that the VAT reform reduces firms' coal and total energy intensities by approximately 9% and 30%, respectively. The effect of the reform is stronger for firms in energy-intensive industries, large-scale firms, and privately owned firms, which have more ability and motivation to purchase new equipment to comply with the VAT reform policy.

Our study shows that an economic policy that provides firms with tax incentives is likely to have a broad effect on firms and promote energy efficiency. Compared with the previous energy policies, which directly influenced the energy price, the VAT reform affects the relative price of capital to energy, which achieves improvements in energy efficiency. Our study sheds new light on economic policy evaluation and provides a new perspective for formulating energy policies. From the perspective of social welfare, however, we cannot conclude that VAT reform is a perfect intervention because the policy also has costs. That is, the decrease in capital prices may have a negative effect on employment and lead to lost tax revenue for the government.

Several directions for future research should be noted. First, other energy policies could be included with the VAT reform in a unified model to conduct a comparative static analysis of its effect on social welfare. Second, if more comprehensive data can be acquired, the VAT reform's potential effect on firms' employment, innovation, and total factor productivity can be explored further. Third, evaluating the impact of tax incentives on air pollution is also an interesting topic that could shed light on socioeconomic and environmental policies. Finally, the implied elasticity of substitution between energy and capital induced by the VAT reform is also worthy of further study.

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[17] Notably, the VAT reform also has some undesirable effects. For example, it leads to a decline in government revenue (Liu and Mao, 2019). Moreover, it causes a distortion in the relative factor prices, which causes a substitution between labor and capital that negatively impacts the labor market and employment (Chen et al., 2010).

Appendix A

Table A1
Industry code and industry name comparison table.

Industry code	Industry name	Observations
B	Mining industry	10,166
C	Manufacturing industry	145,656
D	Production and supply of electricity, heat, gas and water	5110
E	Construction industry	1594

Table A2
Firms' responses to the VAT reform: sensitivity test.

Variables	(All industries)	(All industries)	(All industries)	(Manufacturing-only)
	coalint	*coalint*	*coalint*	*coalint*
reform-new	−0.0276***	−0.0277***	−0.0279***	−0.0184***
	(0.007)	(0.007)	(0.007)	(0.007)
lngdppc		−0.0232	−0.0231	−0.0016
		(0.021)	(0.021)	(0.020)
lnasset		0.0243	−0.0076	−0.0023
		(0.025)	(0.005)	(0.005)
lnasset^2		−0.0016		
		(0.001)		
lnage		−0.0009	−0.0006	−0.0015
		(0.006)	(0.006)	(0.006)
roa		−0.0926***	−0.0918***	−0.0987***
		(0.020)	(0.020)	(0.023)
Observations	167,459	167,459	167,459	149,194
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
R-squared	0.622	0.622	0.622	0.514

Robust standard errors in parentheses.
*** $p < 0.01$.

Table A3
The details of the SO_2 sewage charge reform.

Province	The beginning time of reform	The price before the reform	The price after the reform
Jiangsu	2007.7.1		1.26 yuan/kg
Anhui	2008.1.1		1.26 yuan/kg
Hebei	2008.7.1		1.26 yuan/kg
Shandong	2008.7.1		1.26 yuan/kg
Inner Mongolia	2008.7.10		1.26 yuan/kg
Guangxi	2009.1.1		1.26 yuan/kg
Shanghai	2009.1.1		1.26 yuan/kg
Yunnan	2009.1.1	0.63yuan/kg	1.26 yuan/kg
Guangdong	2010.4.1		1.26 yuan/kg
Liaoning	2010.8.1		1.26 yuan/kg
Tianjin	2010.12.20		1.26 yuan/kg
Xinjiang	2012.8.1		1.26 yuan/kg
Beijing	2014.1.1		10yuan/kg
Ningxia	2014.3.1		1.26 yuan/kg
Zhejiang	2014.4.1		1.26 yuan/kg

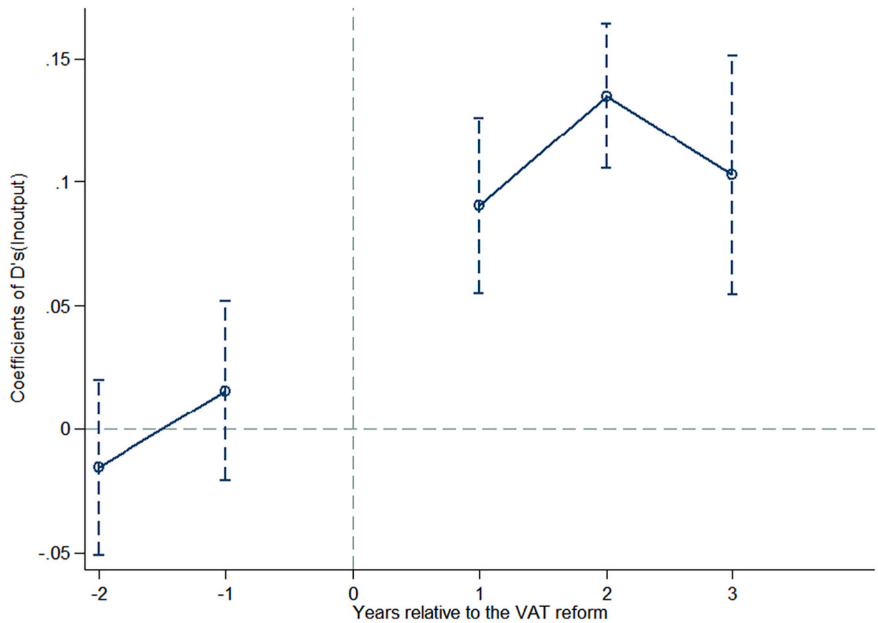

Fig. A1. The parallel trend test of output.

Appendix B. Supplementary material

Supplementary material to this article can be found online at https://doi.org/10.1016/j.eneco.2022.105887.

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