Trade Liberalization, Energy-Saving Technological Change and Energy Intensity: Some empirical evidence from China

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Abstract: This paper discusses the transmission mechanism and effects that trade liberalization influences energy intensity through energy-saving technological change (ESTC). We construct panel data from manufacturing industries in China over the period of 1994-2017, thereby conducting empirical tests through mediation models and discontinuity regression models. The results find that trade liberalization significantly promotes the lowering of energy intensity through ESTC. Heterogeneity test results show that the trade liberalization effect is higher in industries with low barriers to entry and industries with high-pollution. Fuzzy Regression Discontinuity (FRD) results show that energy intensity decreasing as China's accession to the WTO.

Keywords: Trade liberalization; Energy-saving technological change; Energy intensity

JEL Classification: F10; F18; L60; Q43

1. Introduction

Since 1990s', China has implemented trade liberalization reforms that primarily reduce tariffs and lower non-tariff barriers. After joining in the WTO, China's simple average tariff rate fell drastically from 17.4% in 2000 to 9.8% in 2017, a rate lower than the average tariff rate of the developing countries[1]. During this period, China's import, export trade and FDI grew rapidly. From 2001 to 2017, China's export trading volume grew by nearly sevenfold, from $266 billion to $2.263 trillion, making it the largest export trading country in the world. China's imports grew by an average of 13.5%, twice as fast as world imports[2]. *The World Investment Report* (2019) shows that the total amount of FDI attracted by China rose by 4 percent to US $139 billion in 2018, remaining firmly the second largest foreign investment inflow country in the world.

While trade liberalization has decreased trading costs, promoted the expansion of production capacity and trade growth, it has also resulted in a surge in energy consumption (Mitchener and Yan, 2010; Anwar and Sun, 2012). According to the data from the *BP Statistical Review of World Energy*, China was the largest energy-consuming country in the world in 2016, accounting for 23% of the world's energy consumption and 27% of the growth in global energy consumption. Moreover, China's coal consumption volume has reached 26 million tons of oil equivalents, and petroleum consumption has also demonstrated a large growth, with daily consumption volume increased by 400,000 barrels. In 2018, China's petroleum consumption increased by an average of 680,000 barrels per day, making it the fastest growing country in the world.

Trade liberalization has undoubtedly driven the expansion of production capacity, which has

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[1] Tariff data comes from the WTO tariff database.

[2] Import trade and export trade data come from the annual *China Statistical Yearbook* and WTO database.

in turn promoted the growth of energy consumption. Some scholars have found that trade liberalization promotes energy consumption, based on national, industry and enterprises level data (Ghani, 2012; Koengkan, 2018). We are concerned with whether trade liberalization would result in lowered energy intensity. Because lowered energy intensity occurs concomitantly with increased energy efficiency, this ensures the realization of energy conservation and emission reduction, as well as protection of the ecological system. Figure 1 reflects the increases of China's energy consumption from 1980 to 2017. Figure 2 illustrates the declining trend of energy intensity in China (1990-2015). At the same time, compared with the global average energy intensity, energy intensity in China has a large downward trend.

We will discuss the functional mechanisms and effects of trade liberalization on China's energy intensity (Grossman and Krueger 1995; Cole and Elliott 2003; Rafiq et al., 2016). If trade liberalization was proved to promote a decrease in China's energy intensity, it would provide new support for China as the country further implements trade liberalization strategies. Conversely, if trade liberalization drives an increase in energy intensity, a solution to lower energy intensity needs to be found. And China needs to reconsider foreign trade policies for the coordination between energy policies and trade policies.

Some literature has pointed that technological progress plays a leading role in slowing pollution emissions and reducing energy intensity (Popp, 2002; Karanfil and Tamsamani. 2010; Wang, 2020). The paper tries to answer whether trade liberalization affects energy intensity through energy-saving technological change (ESTC). In the case of given output, energy inputs will be reduced in the production process[3]. So, ESTC plays a key role in reducing energy intensity.

The paper constructs both mediation model and fuzzy regression discontinuity (FRD), using 1994-2017 panel data from 27 manufacturing industries in China. The results find that trade liberalization significantly promotes the lowering of energy intensity through ESTC. Heterogeneity test results show that the trade liberalization effect is higher in industries with low barriers to entry and industries with high-pollution. China's entry into the WTO provides an institutional breakpoint. Fuzzy regression discontinuity (FRD) results show that energy intensity decreasing as China's accession to the WTO.

Based on the previous studies, the novel aspects of this paper include the following areas: First, this paper discusses the influencing mechanisms of trade liberalization on energy intensity. To do so, a mediation model is constructed that examines the transmission mechanism of energy intensity affected by trade liberalization through ESTC. Second, this paper goes beyond simply studying the average effects of trade liberalization on energy intensity changes. We also examine the industrial heterogeneity of trade liberalization affecting energy intensity. Third, China has begun to drastically reduce tariff and non-tariff barriers after having joined the WTO. The paper adopts Fuzzy Regression Discontinuity (FRD) to investigate the energy intensity effects as China's accession to the WTO.

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[3] The industries with high degree of market opening are facing fierce market competition, which promotes the adoption of energy-saving technologies, thus resulting in ESTC. We take the wood processing industry as an example. The energy consumption of wood drying accounts for 40%-70% of the total energy consumption of wood processing. At present, solar energy storage technology is widely used in this industry to improve the heat utilization ratio of the whole heating system by using the heat energy or waste heat in the heating process. The application of new energy-saving technology reduces the energy consumption of wood drying and shows ESTC obviously. This example is also consistent with the ESTC results calculated in this paper.
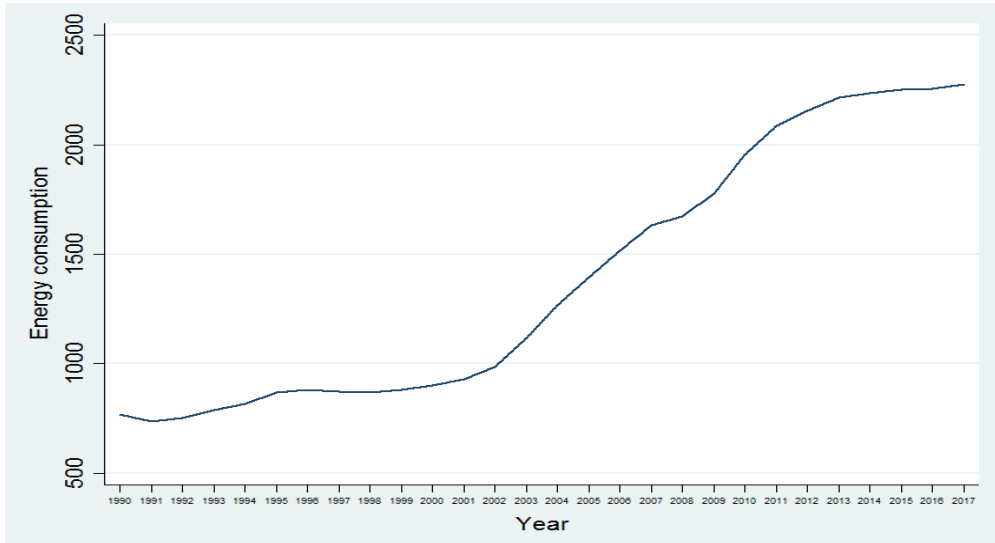
Fig1. Energy Consumption Treads in China (Ten thousand of standard coal).
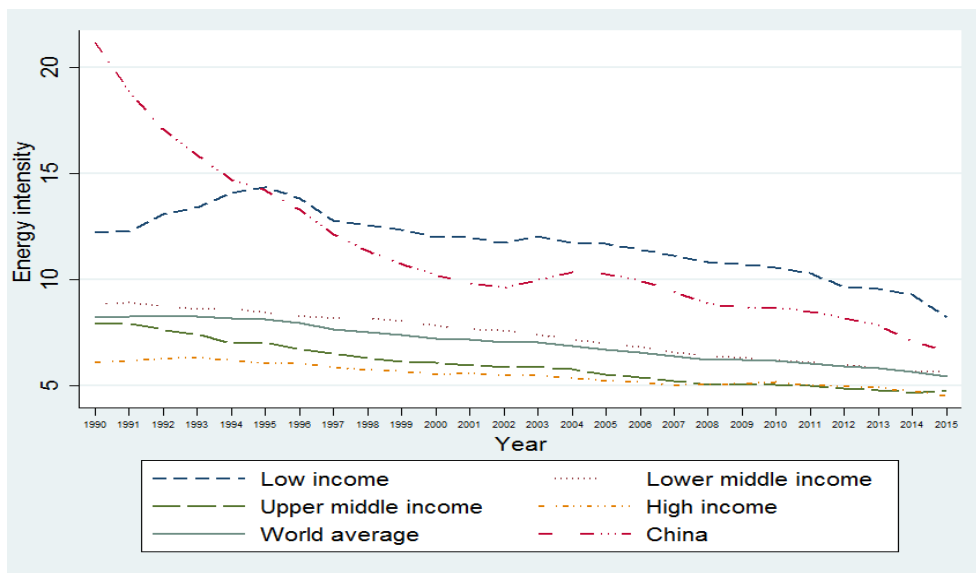
(Data sources: World Bank database)

Fig 2. Energy Intensity Treads in the world (MJ/$2011 PPP GDP)

(Data sources: World Bank database)

2.   Literature Review

A number of recent studies have investigated the impact of trade liberalization on energy consumption, energy efficiency and pollution emissions (Managi et al., 2009; Hossain, 2011; Shafiei and Salim, 2014; Kasman and Duman, 2015). In the literature, two lines of thought have emerged about the impact of trade liberalization on the energy consumption. The researchers with the thoughts of the first stream argue that trade liberalization increases the consumption of energy. For instance, Cole (2006) using World Bank data, Gumilang et al. (2011) studying on Indonesia data and Alessandrini et al. (2011) studying on India data find that trade liberalization promotes energy consumption growth. Sadorsky (2011) identifies that trade liberalization promotes energy

consumption growth in the short and long run in a sample of 8 Middle Eastern countries over the period of 1980-2007. Nasreen and Anwar (2014) find a positive bidirectional relationship between trade liberalization and energy consumption based on 15 Asian countries in 1980-2011. Koengkan (2018) demonstrates that trade liberalization have a positive effect on energy consumption in a sample of four Andean community countries over the period of 1971-2014. However, the researchers with second stream thoughts suggest that trade liberalization decreases the energy consumption. For example, Sbia et al. (2014) investigate the United Arab Emirates (UEA), Shahbaz et al. (2013) investigate Indonesia and find that trade liberalization reduces the consumption of energy. Hübler and Keller (2010) find that it is not possible to robustly conclude whether energy consumption decreases or increases because of the FDI inflows arising from trade liberalization on developing countries. Ghani (2012) contend that trade liberalization has different degrees of influence on the energy consumption in the developed and developing countries. Trade liberalization results in the growth of energy consumption among developing countries, whereas it promotes lowering energy consumption and energy intensity in the developed countries.

Scholars have also studied the mechanism of trade liberalization affecting the energy intensity. Grossman and Krueger (1995) firstly proposed "size, technology, and structure" analysis framework to study the environmental effects of trade liberalization. Cole and Elliott (2003) as well as Cole (2006) then apply this analytical paradigm to study the effect of trade liberalization on energy consumption, namely studying the mechanisms that trade liberalization influences energy consumption through market size, industrial structure, and technological change. They find that trade liberalization promotes the expansion of market size, causing an increase in energy consumption, whereas technological change resulting in lowered energy consumption. Besides, the structure effect of trade liberalization refers to energy consumption changes determined by industrial structure changes. If trade liberalization results in the transfer or elimination of energy-intensive industries, then energy consumption will be reduced. Otherwise, trade liberalization may result in higher energy consumption. In this analytical framework, many scholars have used data from different countries and regions to perform empirical tests. Early literature includes the following: Copeland and Taylor (2004), Perkins and Neumayer (2005), Stern (2007). Some Chinese scholars have embarked on relevant studies in recent years. Zhang (2009) constructs an input-output table in China from 1987 to 2006 to study the effects of the opening up of trade on Chinese energy consumption. The study find that the market size effect promoting growth in energy consumption, whereas technological changes lowering energy consumption. Xu and Yin (2016) analysis the relationship between the degree of trading openness and energy consumption of various provinces, find that the greater the trade openness, the higher the energy efficiency under the condition that the size effect is less than the combined technological effect and structure effect.

Scholars have recognized the important role of technological change in reducing energy consumption. However, technological change is only regarded as changes in general total factor productivity (TFP), or changes in emission specific technology. They fail to consider the impact of ESTC on energy consumption (Ghirmay et al. 2001; Copeland and Taylor 2003). If trade liberalization results in ESTC, it will decrease energy consumption by relatively increasing energy efficiency and energy marginal productivity. Conversely, energy-augment technological change will increase energy consumption (Acemoglu, 2002). As such, ESTC is the core variable to explain lowered energy consumption.

In addition, most studies focused on the relationship between trade liberalization and energy

consumption rather than energy intensity. The most recent study involving trade liberalization and energy intensity is based on the following literature. Managi et al. (2009) investigate the impact of trade openness on environmental degradation in OECD countries in a period of 1971 to 1996. The empirical evidences point that the trade openness improves the environmental quality in OECD countries, because of reducing the energy consumption and energy intensity from fossil fuels. Rafiq et al. (2016) investigate the impact of both urbanization and trade liberalization on emissions and energy intensity for twenty-two emerging economies by using contemporary panel data. They find that trade liberalization significantly reduces both pollutant emissions and energy intensity, whereas urbanization significantly increases energy intensity.

The existing literature does not examine the existence of ESTC in China's industrial sector. Does trade liberalization affect energy intensity through ESTC? This paper studies the effect of trade liberalization on energy intensity through ESTC. The research focuses on both the direct impact and the transmission mechanism.

3. Empirical design

3.1 Empirical Models

To study whether trade liberalization influences energy intensity through ESTC, the mediation model will be used to identify the transmission paths. The following three regression equations are constructed:

$$EI_{it} = \beta_0 + \beta_1 Tariff_{it} + X_{it}\beta + \eta_i + \varphi_t + \varepsilon_{it} \tag{1}$$

$$ESTC_{it} = \alpha_0 + \alpha_1 Tariff_{it} + X_{it}\alpha + \kappa_i + \phi_t + \xi_{it} \tag{2}$$

$$EI_{it} = \theta_0 + \theta_1 Tariff_{it} + \theta_2 ESTC_{it} + X_{it}\theta + \gamma_i + \mu_t + \zeta_{it} \tag{3}$$

In this equation, EI_{it} represents the energy intensity of industry i during period t, which is represented as the ratio of the energy consumption volume to the total industrial sales. $Tariff_{it}$ is the trade liberalization represented by the tariffs of industry i. $ESTC_{it}$ represents the mediation variables (ESTC). X is the control variable. $\eta_i, \kappa_i, \gamma_i$ are the fixed industry effect, φ_t, ϕ_t, μ_t are the fixed time effect, and $\varepsilon_{it}, \xi_{it}, \zeta_{it}$ are the random error term.

The first step is to estimate the model (1). If β_1 is significantly positive, trade liberalization promotes decrease in energy intensity. The second step is to estimate the model (2) and examine the relationship between trade liberalization and mediation variables. Finally, the model (3) is estimated. When α_1, θ_2 are significant and θ_1 is not significant, there is a complete mediating effect. If θ_1 is significant, there is a partial mediating effect. The effect of trade liberalization on energy intensity is only partially achieved through the mediation variables (ESTC).

At the end of 2001, China began to drastically reduce tariff and non-tariff barriers, and trade liberalization level has greatly increased because of joining the WTO. China's entry into the WTO

provides an institutional breakpoint. In this way, the exogenous institutional breakpoint distributes samples to both sides of the breakpoint according to a pre-determined rule, thus creating the effect of natural experimentation. Regression discontinuity (RD) can be used to evaluate the impact of trade liberalization. RD can be divided into sharp regression discontinuity (SRD) and fuzzy regression discontinuity (FRD). In order to fulfill the commitments of China's accession to the WTO, tariff reduction shall be implemented in different sectors and stages. Moreover, not all industries will be affected by the "free trade policy" at the same time after joining the WTO. Therefore, not all industries will enter the treatment group after 2002. Therefore, the paper intends to adopt Fuzzy Regression Discontinuity (FRD) to investigate the energy intensity effects as China's accession to the WTO (which is a non-continuity policy).

3.2 Variable Design

1. Trade liberalization (Tariff)

Trade liberalization includes lowered tariffs and the reduction of various non-tariff barriers. The non-tariff barriers are used to measure the degree of trade liberalization in the robustness test. Import input tariffs are adopted as the measure of trade liberalization in the test. Input tariffs describe the average tariffs on inputs required for production in various industries. As each industry may import a wide variety of products, import input tariffs are more representative of the trade liberalization level than those on output tariffs. Since the UNCTAD database provides import output tariff data of HS 6-digit code production, it is necessary to convert the output tariff into the input tariff. According to the methodology of Amiti and Konings (2007), the input tariffs are the weighted average of the output tariffs. The input tariffs for of industry i of year t are represented as:

$$Tariff_{it} = \sum_g \alpha_{gi} * Outputtariff_{gt} \tag{4}$$

In this equation, a_{gi} (coefficient of input-output matrix) represents the cost share of g industry products in the production of i industry products, that is, $\alpha_{gi} = \frac{Input_{gi}}{\sum_g Input_{gi}}$, $Outputtariff_{gt}$ is the output tariff.

2. Energy-saving technological change (ESTC)

Most scholars use indirect estimation methods to measure the factor-biased technological change. For example, Michaels et al. (2010) indirectly measures capital-augment technological change with computer penetration rate and information capital rate. Caselli (2014) measures skill-biased technological change with industry-level machine equipment price. The paper directly measures the index of ESTC based on cost function.

This paper establishes a production system composed of n factors, $y = f(x_1, \cdots x_n, t)$. Where $x_j (j = 1, \cdots n)$ represents the input quantity of the factor j, and t represents technological change. Using the duality theorem, the cost equation containing non-neutral technological change is $C = g(p_1, \cdots p_n, y, t)$, where $p_j (j = 1, \cdots n)$ represents the price of factor j. Without prior constraints, various specific forms of equations can be established. The paper establishes the transcendental logarithmic cost equation:

$$\ln C^i_t = \rho^i_0 + \sum_j \rho^i_j \ln p^i_j + \frac{1}{2}\sum_j \sum_{j'} \rho^i_{jj'} \ln p^i_j \ln p^i_{j'} + \sum_{j=1} \rho^i_{jy} \ln y^i \ln p^i_j +$$

$$\sum_j \rho^i_{jt} t \ln p^i_j + \rho^i_y \ln y^i + \frac{1}{2}\rho^i_{yy}(\ln y^i)^2 + \rho^i_{yt} t \ln y^i + \rho^i_t t + \frac{1}{2}\rho^i_t t^2 \tag{5}$$

The paper assumes that the final production section (i) requires four factors (j): capital (K), labor (L), energy (E), and intermediate products (M). The cost equation $C(p,Y,t)$ depends on the factor price, output level, and time variables. The cost equation is constructed as the translog cost equation: $j, j' = K, L, E, M$, C is production cost, $p_j, p_{j'}$ stands for factor price. Factor share equation S_j:

$$S^i_j = \rho^i_j + \sum_j \rho^i_j \ln p^i_j + \rho^i_{jt} t + \vartheta_i \tag{6}$$

If $\rho^i_j = 0$, technological change is neutral; $\rho^i_j \neq 0$, technological change is biased (among them, $\rho^i_j < 0$ means factor-saving technological change, $\rho^i_j > 0$ means factor-augment technological change).

Without loss of generality, model (7) satisfies the following constraints: （1）homogeneity：
$$\sum_j \rho^i_j = 1; \sum_{j'} \rho^i_{jj'} = \sum_j \rho^i_{jy} = \sum_j \rho^i_{jt} = 0; \text{（2）symmetry：} \rho^i_{jj'} = \rho^i_{j'j}, \rho^i_{jy} = \rho^i_{yj};$$

（3）monotony：$\dfrac{\partial \ln C^i_t}{\partial \ln p^i_j} = S^i_j \geq 0$；（4）local concavity.

In this paper, technological progress is regarded as a dynamic process, that is, it changes with time. The invariant time trend variable in (6) is replaced by an unobservable variable (latent variable) in a state space model. The non-observable latent variable is estimated by the Kalman Filter method：

$$Z^j_t = C^j Z^j_{t-1} + \theta^j_t \tag{7}$$

$$Y_t = A^j X^j_t + Z^j_t + \varepsilon^j_t \tag{8}$$

With: $\begin{bmatrix} \mu^j_t \\ w^j_t \end{bmatrix} \sim IND \begin{bmatrix} 0 & Q^j \\ 0 & \lambda^j Q^j \end{bmatrix}; \ \lambda^j = R^j / Q^j$

Y_t, X_t are the vector forms of observed, explanatory variables. Z_t is the vector forms of latent variable. Both A and C represent constant matrices, θ_t and ε_t are the Gaussian independent disturbance with R and Q as covariance matrices. λ is a diagonal matrix. The (6) formula is converted to the following state-space model:

$$Y_t = \begin{pmatrix} S_{Kt} \\ S_{Lt} \\ S_{Et} \end{pmatrix}; X_t = \begin{pmatrix} 1 \\ \ln p_{kt} - \ln p_{Mt} \\ \ln p_{Lt} - \ln p_{Mt} \\ \ln p_{Et} - \ln p_{Mt} \\ \ln y_t \end{pmatrix}; Z_t = \begin{pmatrix} \rho_{Kt} \\ \rho_{Lt} \\ \rho_{Et} \end{pmatrix}$$

$$A = \begin{pmatrix} \rho_K & \rho_{KK} & \rho_{LK} & \rho_{KY} \\ \rho_L & \rho_{KL} & \rho_{LL} & \rho_{LY} \\ \rho_E & \rho_{KE} & \rho_{LE} & \rho_{EY} \end{pmatrix}; C = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$$Q = \begin{pmatrix} \mathrm{var}(\varepsilon_t^K) & 0 & 0 \\ 0 & \mathrm{var}(\varepsilon_t^L) & 0 \\ 0 & 0 & \mathrm{var}(\varepsilon_t^E) \end{pmatrix}; R = \begin{pmatrix} \mathrm{var}(\theta_t^K) & 0 & 0 \\ 0 & \mathrm{var}(\theta_t^L) & 0 \\ 0 & 0 & \mathrm{var}(\theta_t^E) \end{pmatrix}$$

Kalman filtering includes filtering stage and smoothing stage. The unknown variable (ρ_{jt}) can be estimated using MLE (Maximum Likelihood Estimation) and recursive method respectively. $\rho_{Et} < 0$ means energy-saving technological change (ESTC), and $\rho_{Et} > 0$ means energy-augment technological change.

Table 1 reports the result of ESTC. The results show that most of the industries in China have energy-saving technological change except 1industries (oil processing industry). The average value of ESTC is -0.0512, which reflects the overall existence of ESTC in China. Among them, paper products industry, wood processing industry, Chemical materials and food manufacturing industry have the highest ESTC. These industries are raw materials-intensive industries, using more raw materials and relatively less energy in production. Energy intensity is relatively low in these industries. ESTC of communication equipment industry and general equipment industry are relatively small, the average value is near 0. These industries are generally energy-intensive industries and may require more energy input in the production process. Energy efficiency is relatively lower than other factors.

Table1. The result of ESTC

industry	ESTC	industry	ESTC	industry	ESTC
Food manufacturing	-0.1345	Pharmaceutical manufacturing	-0.1001	Oil processing	0.1235
Beverage manufacturing	-0.0736	Plastic products	-0.0412	Chemical materials	-0.1408
Tobacco processing	-0.0355	Metal products	-0.0013	Chemical fiber	-0.0196
The textile industry	-0.0414	General equipment	-0.0009	Rubber products	-0.0503
Clothing, shoes and hats	-0.0158	Special equipment	-0.0513	Nonmetallic mineral	-0.0871
Leather hairiness	-0.0361	Transportation equipment	-0.0445	Black metal	-0.0333
Wood processing	-0.1429	Electrical machinery	-0.0274	Nonferrous metal	-0.0595
Furniture manufacturing	-0.0516	Communication equipment	-0.0004		
printing industry	-0.1104	Instrument and meter	-0.0112		
Cultural and educational supplies	-0.0113	Paper products	-0.1846		

3. Control variables

To improve the reliability of the estimated results, control variables were added: (1) Market size (Scale): It is represented as the added value of various industries, which is then processed logarithmically. (2) Factor structure (KL): It is represented as the capital-labor ratio, which is then processed logarithmically. (3) Environment regulatory intensity (ERI): It is represented as the ratio of the wastewater management fees to the added value of various industries. Environmental regulation will increase the operating cost of polluting enterprises, which will encourage enterprises to accelerate technological innovation and reduce energy intensity. (4) Foreign direct investment (FDI): FDI promotes domestic enterprises to improve technology and reduce energy consumption through technological spillovers and learning effects. So it is represented as the ratio of FDI to the industrial added value of various industries. (5) Ownership structure (OS): It is represented as the ratio of state capital to the industry owner's equity of various industries. Different ownership structure is very different from management mode and incentive mechanism, and it also has a significant impact on energy efficiency.

3.3 Data

This paper uses samples from the sub-sectors of 27 manufacturing industries over the period of 1994-2017. The import tariff data for HS6-digit code products are taken from the WTO database (i.e. Tariff Download Facility). According to the conversion tables (HS1996 and HS2002, HS2007 and HS2002, HS2012 and HS2002) provided by the United Nations, tariffs data for different years are unified into HS2002. According to the conversion relationship between HS2002 and GB / T2002, the industry level tariff can be calculated by using the product level tariffs data of HS2002.

The relevant variables are explained as follows for the estimation of ESTC:① The Capital Price (p_k) is selected as the fixed assets investment price index in each year. ② The labor price (p_L) is expressed as the average wage index of each industry. ③ Energy prices (p_E). Because each industry's energy consumption is measured in standard coal, the price of coal represents the energy price. ④ capital stock (K). This paper uses perpetual inventory method to estimate the capital stock, and convert the fixed assets investment into capital stock in each year. ⑤ The number of labor (L) is expressed by the number of employed persons at the end of the year in each industry, and the total labor cost is expressed by the total amount of actual wages in each industry. ⑥ energy consumption (E) is the amount of energy consumption in each industry.

The above data are taken from *China Statistical Yearbook*, *China Labor Statistical Yearbook*, *China Energy Statistical Yearbook*, and *China Price Yearbook*. The data of ERI in the control variables were obtained from *China Environmental Statistical Yearbook*. The other data in the control variables were calculated from the relevant data in *China Statistical Yearbook*. Table 2 presents the descriptive statistics of the major variables.

Table2. Descriptive Statistics

Variable	Definition	Mean	Standard deviation	Min	Max
Tariff	The input tariffs for of industry	0.0484	0.0216	0.0076	0.1318
ESTC	Energy-saving technological change	-0.0512	0.0601	-0.1846	0.1235
EI	the energy intensity of industry	0.0172	0.0250	0.0006	0.1535

Scale	the added value of industry and take the logarithm	8.5949	1.3709	5.3881	11.5202
KL	the capital-labor ratio of industry and take the logarithm	3.0062	1.5692	0.3745	6.1014
ERI	the ratio of the wastewater management fees to the added value of various industries	0.0052	0.0114	1.72971	4.9260
FDI	the ratio of FDI to the industrial added value of industry	0.1771	0.0967	0.000023	0.4923
OS	the ratio of state capital to the industry owner's equity of industry	0.0709	0.0823	0.000028	0.5971

4. Analysis of Empirical Findings

4.1 Benchmark Regression

Table 3 shows the regression results based on the mediation model (1)-(3). Columns (1) to (3) of Table 3 are estimation results that do not contain double fixed effect, Columns (4) to (6) are estimated results that contain industry fixed effect and time fixed effect. The estimated trade liberalization parameter values are 0.3203 and 1.7508 based on the model (1). If tariff is reduced by 1 unit, energy intensity will be reduced by 32.02% and 175.08%, respectively. The result shows that there is a significantly positive relationship between tariff and energy intensity. In other words, reduced tariff rates and increased trade liberalization promotes a reduction in energy intensity. Next, the paper examines the relationship between trade liberalization and ESTC based on model (2). The results show that trade liberalization is beneficial to strengthening energy-saving technological change[④]. Columns (3) and (6) report the estimated results according to model (3). The parameter values of trade liberalization are 0.2777 and 1.6213, which decreases relative to Columns (1) and (4). According to the judgment method of the mediation model, it can be concluded that trade liberalization lowers energy intensity through energy-saving technological change.

The estimation results of control variables mostly accord with the theoretical expectation. For instance, Market size (Scale) promotes the declining of energy intensity. With the increase of capital-labor ratio (KL), FDI and environmental regulation index (ERI), it helps to reduce energy intensity. The proportion of state-owned (OS) is positively correlated with energy intensity.

Table3. Estimation results of benchmark regression

	EI	ESTC	EI	EI	ESTC	EI
	(1)	(2)	(3)	(4)	(5)	(6)
Tariff	0.3203***	0.2694**	0.2777**	1.7508***	0.5092**	1.6213**
	（2.83）	（2.23）	（2.04）	（2.71）	（2.28）	（2.27）
ESTC			0.1683***			0.5793**
			（5.95）			（2.09）
lnScale	-0.2231***	-0.0004***	-0.2312***	-0.3522***	-0.0066***	-0.3483***
	(-8.34)	（-3.11）	（-8.96）	（-4.75）	（-2.51）	（-4.72）
KL	-0.0049***	-0.0002**	-0.0040***	-0.0039***	-0.0001***	-0.0038***

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④ The part of estimated results is not reported.

	(-4.17)	（-2.26）	（-3.52）	（-3.46）	（-2.87）	（-3.38）
ERI	-0.0001*	-0.0007*	-0.0001**	-0.0003***	-0.0001***	-0.0003***
	（-1.84）	（-1.81）	（-2.22）	（-7.61）	（-2.54）	（-7.69）
FDI	-2.4835***	-0.0204***	-2.5141***	-1.0364*	-0.0088**	-1.0415**
	(-6.39)	（-3.03）	（-6.71）	（-1.97）	（-2.09）	（-1.98）
OS	0.6603**	0.0106	0.6032*	0.3125*	0.0017	0.3115
	（2.02）	（0.24）	（1.92）	（1.91）	（0.87）	（1.41）
Industry fixed effect	No	No	No	Yes	Yes	Yes
Time fixed effect	No	No	No	Yes	Yes	Yes
Observations	486	486	486	486	486	486
R-squared	0.5279	0.4597	0.5335	0.8658	0.8932	0.8811

Note: (1) ***p<0.01, **p<0.05, and *p<0.1; (2) t-values are reported in parentheses. (3)Indirect effect is 0.0453, direct effect is 0.2777, and total effect is 0.323, according to the regression results in Columns (1) to (3). Indirect effect is 0.2950, direct effect is 1.6213, and total effect is 1.9163, according to the regression results in Columns (4) to (6).

4.2 Heterogeneity Testing

In this section, we will carry out heterogeneity testing. We divide samples into high entry barrier industries and low entry barrier industries, or into high pollution industries and low pollution industries. In reality, when market barriers to entry are low, trade liberalization intensifies market competition and promotes technological innovations, thereby lowering energy intensity. Conversely, when market barriers to entry are high, the effects from the technological innovations of trade liberalization are limited. To verify this opinion, this paper performs heterogeneity testing on the transmission paths of trade liberalization based on relative barriers to entry. Meanwhile, this paper uses industry ownership structures as a basis to categorize the barriers to entry. If the proportion of state capital for the industry is higher than the average proportion of state capital for all industries, the industry is defined as one with high barriers to entry.[5] Otherwise, the industry is recognized as one with low barriers to entry. Twelve industries had high barriers to entry: tobacco, printing, petroleum processing, coking and nuclear fuel processing, chemical materials and chemical product manufacturing, chemical fiber manufacturing, rubber product manufacturing, non-metal mineral product manufacturing, ferrous metal smelting and calendaring, non-ferrous metal smelting and calendaring, general equipment manufacturing, special equipment manufacturing, and transportation equipment manufacturing. Other industries were defined as having low barriers to entry.

The degree to which trade liberalization impacts energy intensity is also related to the energy consumption and pollution discharge of the industry. If the industry in question is a low-pollution one, the energy consumption intensity is low, and the degree to which trade liberalization impacts its energy intensity is low. In contrast, if the said industry is a high-pollution one, the degree to which trade liberalization impacts its energy intensity is high. The classification criteria for pollution

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[5] The proportion of state capital is expressed as the proportion of state capital in total capital in various industries. In 2015, the average value of state capital proportion is 8.92%.

industries are based on the various industries' CO_2 emission coefficients. This indicator is the product of the direct CO_2 emission coefficient multiplied by the Leontief inverse matrix. Industries with values for this indicator that are higher than its average value for all industries were defined as high-pollution industries, whereas those with values for this indicator that are lower than its average value for all industries were defined as low-pollution industries. There were nine high-pollution industries: paper and paper products, petroleum processing and coking, chemical raw materials and chemical products manufacturing, chemical fiber manufacturing, rubber products manufacturing, non-metal mineral product manufacturing, ferrous metal smelting and calendaring, non-ferrous metal smelting and calendaring, and crafts and other manufacturing. Other industries were defined as low-pollution industries.

The first and second columns of Table 4 show the estimation results of how trade liberalization impacts energy intensity among industries with high barriers to entry and industries with low barriers to entry. The trade liberalization parameter values estimated for industries with low barriers to entry were larger than those of industries with high barriers to entry. The results show that trade liberalization plays a greater role in reducing energy intensity among industries with low barriers to entry. The third and fourth columns of Table 4 show the estimation results of how trade liberalization impacts energy intensity among high-pollution and low-pollution industries. The trade liberalization parameter values were significant for both types of industries. In terms of the degree of influence, trade liberalization plays a greater role in helping to reduce energy intensity among high-pollution industries than low-pollution industries. This is also consistent with the predictions.

Table4. Estimation results of heterogeneity testing

	high barriers to entry	low barriers to entry	high pollution	low pollution
	(1)	(2)	(3)	(4)
Tariff	0.4556**	0.7838**	0.9169***	0.6398***
	(2.38)	(2.12）	(4.00)	(2.81)
ESTC	1.1682***	0.9375***	0.9270**	0.6035**
	(4.70)	(5.72)	（4.12）	（2.48）
Control variables	Yes	Yes	Yes	Yes
Industry fixed effect	Yes	Yes	Yes	Yes
Time fixed effect	Yes	Yes	Yes	Yes
Observations	216	270	162	324
R-squared	0.7454	0.7368	0.8412	0.7943

Note: (1) ***p<0.01, **p<0.05, and *p<0.1; (2) t-values are reported in parentheses.

4.3 Fuzzy Regression Discontinuity (FRD)

The basic idea of the FRD is that energy intensity change may be caused by China's accession to the WTO if energy intensity jumps significantly in 2002. This paper first draws a graph of the relationship between energy intensity and running variable. As figure 3 shows, there is a significant jump of energy intensity in 2002. The result initially suggests that joining the WTO can reduce energy intensity in China.
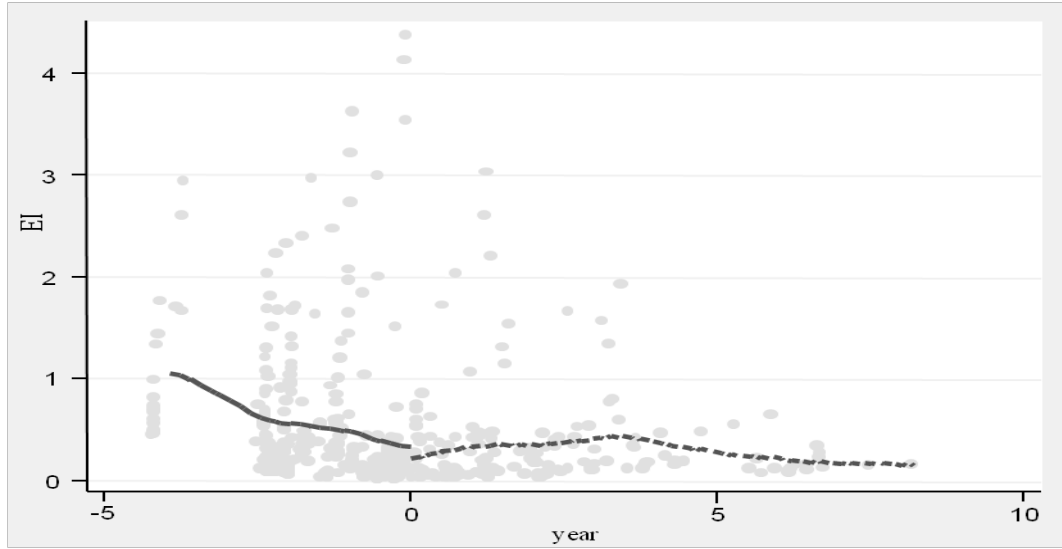
Fig 3. The relationship graph between energy intensity and running variable

Table 5 report the treatment effect of energy intensity after China entering WTO. When the covariables are added in turn, the estimation results do not affect the consistency of the FRD, but it can improve the estimation efficiency. From the estimation results, there is no significant change in the coefficient of treatment variable D, regardless of whether or not covariables are added. The results reflect the robustness of the estimation. The results show that trade liberalization can significantly promote the reduction of energy intensity after China entering the WTO.

Table5. Estimation results of FRD

	EI	EI	EI	EI
	(1)	(2)	(3)	(4)
D	-0.7926***	-0.8118***	-0.9038*	-0.8615**
	(4.12)	(3.36)	(-1.87)	(-2.24)
T_t-T_0	-0.0229***	-0.0199***	-0.0678**	-0.0525***
	（3.34）	(-4.00)	(2.24)	(3.76)
$D(T_t-T_0)$	0.1721***	0.1615***	0.2016***	0.2162***
	(7.79)	(7.15)	(5.39)	(4.98)
ESTC		0.6877***	1.2472*	0.9317**
		(2.94)	(1.93)	(2.22)
lnScale			-0.0003***	-0.0003***
			(-4.12)	(-5.06)
ERI				-0.8090**
				(-2.16)
R-squared	0.4896	0.5203	0.5382	0.5769
Wald	145.66	150.12	159.88	165.72

Note: (1) ***p<0.01, **p<0.05, and *p<0.1; (2) t-values are reported in parentheses.

4.4 Testing for Robustness

The paper will make the robust analysis of the above empirical results. Robust testing includes

three aspects.

First, there may be endogenous problems. Although tariffs at the industry level are largely unaffected by economic, social and other factors within a country, the possibility of a two-way causality between tariffs and energy consumption is small. However, some important policy shocks (such as accession of FTA) may affect both tariffs and energy intensity, resulting in endogenous problems[⑥]. This paper will perform instrumental variable regression in order to eliminate the endogeneity that may be present in trade liberalization variables (Gaston and Trefler, 1997; Beaulieu, 2000). Tariff rate promised by China in the tariff concession table (Annex 8: Schedule CLII) when its entry into the WTO is used as the instrumental variable of trade liberalization.

Second, we should considerate the impact from non-tariff barriers. Trade liberalization does not simply include lowered tariffs but also the reduction of various non-tariff barriers. However, the measurement indicators for non-tariff barriers are not standardized and are quite controversial. This paper adopts an indirect approach to studying non-tariff barriers. Among all of the industries, the textile industries experience the greatest reduction in non-tariff barriers. The impact from non-tariff barriers is eliminated after we exclude the textile industry and re-perform the regression process (Yu and Liang, 2014).

Third, we should considerate potential measurement error problems. The re-measurement of energy intensity: Energy consumption per unit capital (EK) is used to measure energy intensity.

The first column of Table 6 shows the IV estimation results. The trade liberalization parameter values are positive and significant, and there are no significant changes to the coefficients of ordinary least squares (OLS) estimates. The second column shows the regression results after excluding the textile industry, whereas the third column shows the estimation results using energy consumption per unit capital as the independent variable. The finding that trade liberalization helps reduce energy intensity is robust.

Table6. Estimation results of endogenous and robustness tests

	Endogenous	Robustness	
	IV	non-tariff barriers	energy intensity
	(1)	(2)	(3)
Trade liberalization	0.8762***	2.1933***	4.7878***
	(6.23)	(4.88)	(2.72)
ESTC	0.6021***	1.0327***	0.4438*
	(3.48)	(4.17)	(1.77)
Control variables	Yes	Yes	Yes
Industry fixed effect	Yes	Yes	Yes
Time fixed effect	Yes	Yes	Yes
Observations	486	468	486
R-squared	0.7112	0.7629	0.7033

Note: (1) ***p<0.01, **p<0.05, and *p<0.1; (2) t-values are reported in parentheses.

5. Research Conclusions

Whether trade liberalization could result in excessive growth in energy consumption and

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[⑥] FTA means Free Trade Agreements.

pollution among developing countries is an issue of concern among many scholars. This paper studies the transmission mechanisms and effects of trade liberalization on energy intensity. This paper constructs panel data for 27 manufacturing industries in China over the period of 1994-2017, thereby conducting empirical tests through mediation models. The results find that trade liberalization significantly promotes the lowering of energy intensity, and trade liberalization promotes a decrease in energy intensity through ESTC. Heterogeneity test results show that the trade liberalization effect is higher in industries with low barriers to entry and high-pollution industries. Fuzzy Regression Discontinuity (FRD) results show that energy intensity decreasing as China's accession to the WTO (which is a breakpoint). The above results have passed the robust test and endogenous test.

The policy implications from the findings of this paper are as follows. Firstly, Chinese government should accelerate the reform to promote the trade liberalization. China should further open up for trading, lower trade barriers, and refine trade liberalization reforms. Meanwhile, China has to speed up the construction of the domestic market system and effectively link the domestic market with the international market. Secondly, China should vigorously improve the level of ESTC. ESTC has played a direct role in reducing energy intensity, improving energy efficiency and reducing pollution emissions. So, it also needs to actively bring in, assimilate, and absorb advanced foreign technologies, thereby realizing the dual goals of sustainable technological change and energy conservation and emissions reduction. Thirdly, Chinese government should reduce the energy intensity through various policy tools. On the one hand, the government should strengthen environmental regulations to restrict the introduction and expansion of high energy-consuming and highly polluting industries and phase out backward production capacity; on the other hand, local enterprises should be encouraged to import advanced energy-saving and environmental protection technologies and equipment. New energy industries and environmental protection industries should also be encouraged to invest in China.

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