sustainability

MDPI

Article

Impact of Environmental Regulation and Technical Progress on Industrial Carbon Productivity: An Approach Based on Proxy Measure

Huan Zhang * and Kangning Xu

School of Economics and Management, Southeast University, Nanjing 211189, China; xkn@seu.edu.cn
* Correspondence: zhanghuan371@163.com; Tel.: +86-25-5209-0739

Academic Editor: Marc A. Rosen
Received: 11 July 2016; Accepted: 17 August 2016; Published: 19 August 2016

Abstract: This research aims to study the main influencing factors of China's industrial carbon productivity by incorporating environmental regulation and technical progress into an econometric model. The paper focuses on data from 35 of China's industrial sectors and covers the period from 2006 to 2014, in order to examine the impact of environmental regulation and technical progress on carbon productivity. Methods applied include panel fixed effect model, panel random effect model and two stage least squares with instrumental variables (IV-2SLS). The effect of environmental regulation and technical progress has industrial heterogeneity. The paper subdivides industrial sectors into capital and technology intensive, resource intensive and labor intensive sectors according to factor intensiveness. The estimation results of the subgroups have uncovered that for capital and technology intensive and resource intensive sectors, environmental regulation has a more significant impact than technical progress; while for labor intensive sectors, innovation more significantly influences carbon productivity. In addition, foreign direct investment (FDI) and industrialization level facilitate improving carbon productivity for the full sample. By contrast, industrial structure inhibits the overall industrial carbon productivity. The industry-specific results indicate that for capital and technology intensive sectors, optimizing of the industrial structure can improve carbon productivity; for resource intensive sectors, FDI and energy consumption structure should be emphasized more; for labor intensive sectors, industrialization levels help enhance carbon productivity. Finally the industrial sector-specific policy suggestions are proposed.

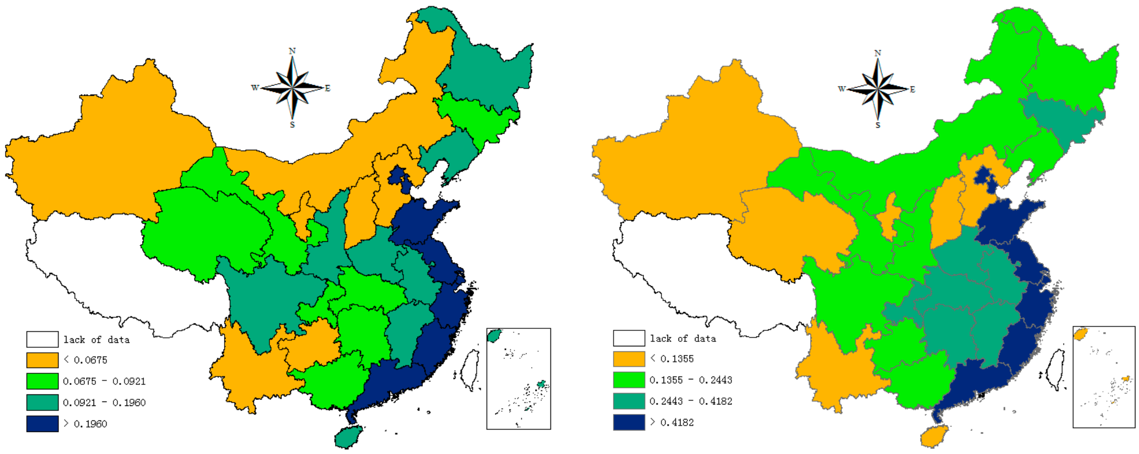
Keywords: environmental regulation; technical progress; carbon productivity

---

1. Introduction

The issue of global climate warming led by CO_2 emission, has increasingly caught the public's attention in recent years. Under the context of low carbon economy, reduction of carbon dioxide has become the common goal of various countries. At the same time, keeping a steady economic growth rate is also the major requirement of each country, especially for developing countries. The only way of achieving the two objectives is to raise carbon productivity. To do so, China plans to reduce its carbon intensity of per capita GDP by 40%–45% at the end of year 2020 when compared to 2005. Thus, China's carbon productivity has to be improved in the next several years. The absolute level of carbon productivity of China is still low in comparison to advanced countries. However, the rate of growth has been pretty high, which shows the potential of carbon reduction and productivity advancement.

As the world's largest developing country and emerging economy, China is now at the critical stage of quick enhancement of industrialization and urbanization. Thus on one hand, given that some pillar industries have high CO_2 emission and high energy consumption rates and have been playing a vital role in supporting the national economy; and it is expected that they will continue to exist for a long period of time, which could lead to a dramatic increase in the demand for energy. On the other hand, China's coal based energy consumption structure has limited the choice of other low-carbon energies. In addition, under the circumstance of rapid urbanization and the economy's new normal, all of these factors bring about extreme challenges in energy saving and emission reduction. Therefore, through strengthening environmental regulation, implementing innovation-driven strategies so as to enhance the level of carbon productivity and eventually achieve the goal of low-carbon development, it has become an important issue that continues to draw attention. This has been the main motivation for writing this paper. Figure 1 depicts the quartile graph of industrial carbon productivity at provincial level (calculation method to be explained in Section 3). We notice that there exists a transformation of industrial carbon productivity across regions. This provincial difference reflects that industrial carbon productivity has regional heterogeneity. Whether or not carbon productivity difference also exists across industrial sectors, is worthy of further investigation. This is another motivation for us to conduct the research. Environmental regulation and technical progress are considered to be the most influential factors as they represent the level of institution and innovation. It has been proven that for countries with a middle income level, the two factors play a significant role in helping sustain middle to high rate of growth. This paper conducts the research aiming to explore the impact direction and range of this on industrial carbon productivity.



(**a**) (**b**)

Figure 1. Industrial carbon productivity at provincial level in (**a**) 2006 and (**b**) 2014.

2. Literature Review

The notion of carbon productivity was first presented by Kaya and Yokobori in 1997 [1]. Carbon productivity incorporates the two targets of low-carbon economy and includes reducing CO_2 emission and sustaining economic growth [2].

The key points of the past relevant literature have concentrated on the following aspects. Some studies focused on the meaning of carbon productivity. First, the importance of improving carbon productivity was highlighted. The loss of environmental efficiency directly leads to the total value of output loss among OECD countries [3]. As the growth rate of CO_2 emissions is negatively correlated with carbon productivity improvement, thus to reduce carbon emissions facilitates enhancement of carbon productivity [4]. Second, the relationship between carbon productivity and carbon intensity was analyzed. Studies results show that it would be possible to decrease carbon intensity while not harming economic performance [5,6]. Third, the meaning of carbon productivity was further extended. Zhou et al. [7] pointed out that carbon productivity is also a production factor which is similar to total factor productivity.

The second kind of literature works conducted comparison analysis of carbon productivity at the regional, industrial and country level. First, for industrial level, the growth in carbon productivity for the transportation sector in China was found to have different modes among Eastern, Central and Western areas [8–10]. The carbon productivity of the Australian construction industry had increased dramatically during the last few decades and may be further enhanced based upon the technological innovation level [11]. Second, as for regional level, industrial structure optimization and utilization of carbon capture and storage (CCS) technology is necessary for low-carbon development of the Yellow River Delta High-efficient Eco-economic Zone in China [12]. Due to the importance of high-emission and low-efficiency industries by classifying industries into four types according to "emissions-efficiency" characteristics, improving energy utilization efficiency is most vital in affecting carbon productivity in Tianjin, China [13]. Third, on the country level, environmental technical change mostly explains the improvement in overall carbon productivity for 20 member countries of the European Union from 1990 to 2003 [14]. A three-dimensional absolute decomposition model was utilized to analyze changes of carbon productivity in China [15].

Other studies explored the factors influencing carbon productivity. Depending on different research purposes, significant influential factors include technology, economic structure, population structure change, domestic demand and exports [16–18]. Considering the influence direction, industrial energy efficiency, opening degree, technological progress and industrial scale structure exert significant positive effects on carbon productivity, while per capita GDP, industrial energy consumption structure and industrial ownership structure have negative effects on industrial-level carbon productivity [19].

The main contributions of the paper are as follows. This research incorporates environmental regulation and technical progress into the econometric model, in order to study the main influencing factors of improving industrial sectors' carbon productivity. In addition, compared to existing literature, this paper makes an additional contribution in considering industrial heterogeneity. We further divide 35 Chinese industrial sectors into capital and technology intensive sectors, resource intensive sectors and labor intensive sectors and then examine, respectively, the impacts on carbon productivity for each type of sector. Through classification and comparison analysis, we can better identify the similarities and differences of the influences. We believe the research results would be conducive to creating a balanced development of industrial sectors and the optimization of industrial structures.

3. Data and Methodology

3.1. Model Specification

Kaya [20] combined CO_2 emission, economic development, energy consumption and population through the factorization method. York et al. [21] utilized STIRPAT model to offer decomposition formula of CO_2 driving force. He mainly explained influencing factors of CO_2 emission in terms of economic structure, technology level, economic development level and population scale. The formula is expressed as follows:

$$E = G \times T \times S \quad (1)$$

where E stands for CO_2 emissions volume, G represents economic activity, T refers to technology level, S denotes population structure. This paper employs STIRPAT model to modify Equation (1) into:

$$E/G = T \times S \quad (2)$$

The left side of Equation (2) is reciprocal of carbon productivity, the right side is population structure and technology levels that influence carbon productivity. Equation (2) can be further transformed into:

$$G/E = 1/(S \times T) \quad (3)$$

Then this paper's econometric model can be established based on Equation (3):

$$\ln(G/E)_{i,t} = \alpha_0 + \beta_1 \ln S_{i,t} + \beta_2 \ln T_{i,t} + \mu_{i,t} \quad (4)$$

where *i*, *t* respectively denotes *i* sector and *t* year; α_0 is constant term; $\mu_{i,t}$ refers to error term; ln is to take natural logarithmic form of the data. *G/E* can also be referred to as carbon productivity. As the momentum of population growth will not be changed within a short period of time, on the basis of considering relevant influencing factors, we bring into environmental regulation and technical progress as core explanatory variables and thus construct an econometric model of affecting factors on China's industrial carbon productivity as follows.

$$\ln CP_{i,t} = \alpha_0 + \beta_1 regu_{i,t} + \beta_2 pat_{i,t} + \gamma Contr + \eta_i + \mu_t + \varepsilon_{i,t} \tag{5}$$

where *CP* represents carbon productivity, *regu* denotes environmental regulation intensity, *pat* stands for technical progress; *Contr* is control variable, includes foreign direct investment, energy consumption structure, industrialization level and industrial structure; η_i is individual effect, μ_t is time effect, $\varepsilon_{i,t}$ is stochastic disturbance.

3.2. Indicators Selection

Carbon productivity (*cp*):

Carbon productivity can be seen as a scarce resource under the "new normal" economy, which is defined as regional GDP divided by CO_2 emission volume at a period of time. We hereby adopt a gross industrial output value (deflated by 2005 producer price index) divided by CO_2 emission volumes according to the research purpose.

As CO_2 emission volume, which is the main component of greenhouse gases, cannot be derived directly, the current research obtains the data mostly through estimation. This paper estimates China's industrial CO_2 emission volume based on the method that is recommended by IPCC (Intergovernmental Panel on Climate Change) in Table 1 and the detailed formula is as follows.

$$CO_{2i,t} = \sum_{j=1}^{n} E_{j,t} \times T_j \times C_j \times R_j \times 44/12 \tag{6}$$

where $CO_{2i,t}$ is CO_2 emission volume in unit of ten thousand tons, *t* denotes year, *j* = 1, 2, 3 ... 8, represents eight types of primary energy, includes coal, coke, crude oil, gasoline, kerosene, diesel oil, fuel oil and natural gas. $E_{j,t}$ stands for real consumption amount of those energy in unit of ten thousand tons of standard coal, T_j refers to calorific value, C_j is carbon emission coefficient, R_i denotes carbon oxidation rate, 3.667 (44/12) is carbon molecular ratio.

Table 1. Calculation of CO_2 Emission Volume.

Energy Name	Standard Coal Coefficient (kg-s.c./kg)	Calorific Value (kJ/kg)	Carbon Emission Coefficient (Ton-Carbon/TJ)	Carbon Oxidation Rate	CO_2 Emission Coefficient (kg-CO_2/kg)
coal	0.7143	20,908	26.37	0.94	1.9003
coke	0.9714	28,435	29.5	0.93	2.8604
crude oil	1.4286	41,816	20.1	0.98	3.0202
gasoline	1.4714	43,070	18.9	0.98	2.9251
kerosene	1.4714	43,070	19.5	0.98	3.0179
diesel oil	1.4571	42,652	20.2	0.98	3.0959
fuel oil	1.4286	41,816	21.1	0.98	3.1705
natural gas	1.3300	38,931	15.3	0.99	2.1622

Note: 1 TJ = 10^9 kJ; Source: IPCC [22] and author calculation.

Environmental regulation intensity (*regu*):

Due to lack of a direct measurement indicator for environmental regulation, the existing literature generally selects different proxy indicators depending on research requirements. Firstly, some researchers used expenditure on pollution treatment and control of unit output to express environmental regulation [23]. Secondly, others used waste discharge amounts for unit output to indicate regulation intensity [24]. Thirdly, per capita income level was also used as a proxy variable for environmental regulation. This paper selects annual expenditure for operation on industrial waste water and gas treatment facility divided by cost of main operation [25].

Technical progress (*pat*):

Over a long period of time, China's high level economic growth was mainly dependent on input of physical factors, i.e., factor-driven mode. Along with the increasing restriction of resource and environment, relying upon traditional way of growth in terms of high input, heavy energy-consuming, high emission and low production efficiency becomes no longer sustainable. The immediate consequence would be the majority of domestic industries still located at the low-end of global value chain. Therefore the country has to enforce innovation-oriented strategy and strengthen national innovation capacity in order to accelerate the transformation of economic development. Patent is the direct reflection of technology level and is also an important indicator for technical innovation ability [26]. Thus this research adopts the number of patent applications to measure industrial technical progress.

Foreign capital dependence (*fdi*):

From the perspective of low carbon economy, entry of foreign capital will bring about a positive effect of boosting GDP growth and at the same time, create a negative effect in terms of certain environmental pollution. If the former outweighs the latter, then utilizing foreign capital helps enhance carbon productivity and vice versa. This paper selects Hong Kong, Macau, Taiwan's capital and actual receipt foreign capital, divided by gross industrial output value as the indicator.

Energy consumption structure (*ecs*):

Generally, provided that non-clean energy constitutes a larger proportion of the total amount of energy consumed, environmental pollutants such as carbon dioxide and sulfur dioxide will be generated more accordingly. Hence carbon productivity will be lowered if the energy consumption structure is mainly using fossil fuel. This paper adopts each industrial sector's coal consumption amount divided by total industries coal consumption amount to represent the energy consumption structure.

Industrialization level (*ind*):

Industrialization is an indispensable phase of low income countries to progress in becoming a high income country. Along with the development of productivity, the price of excessive depletion of resources has also been a high price to pay at the same time. We use the number of employees of each industrial sector divided by the total number of employees of industrial sectors to indicate the industrialization level.

Industrial structure (*stru*):

The current industrial structure of China is characterized by "secondary-tertiary-primary", which means industrial sectors still occupy a dominant place among the three main industries. Generally, secondary industry accounts for the larger share and apparently inhibits the improvement of industrial carbon productivity. Again, secondary industry includes mining, manufacturing, production and distribution of electricity, gas, water and construction industries. The carbon productivity of each sub-industry varies. Thus this paper selects output values of each industrial sector divided by total output value of all industries to represent the industrial structure.

Definition of variables are listed in Table 2. This paper selects 35 sectors out of 39 industrial sectors from 2006 to 2014 consisting of panel data. Due to lack of data, other minerals mining and dressing, recycling and disposal of waste are excluded from the analysis. In consideration of consistency of statistical caliber, this paper integrates the manufacture of rubber and of plastic into the one sector, i.e., manufacture of rubber and plastic; and incorporates the manufacture of artwork into culture, educational and sports goods.

Table 2. Definition of Variables.

Variable	Definition
Carbon productivity (*cp*)	gross industrial output value /carbon dioxide emissions amount
Environmental regulation (*regu*)	annual expenditure for operation on industrial waste water and gas treatment facility /cost of main operation
Technical progress (*pat*)	the number of patent applications
Foreign capital dependence (*fdi*)	Hong Kong, Macau, Taiwan capitals and actual receipt foreign capital /gross industrial output value
Energy consumption structure (*ecs*)	each industrial sector's coal consumption amount /total industries coal consumption amount
Industrialization level (*ind*)	the number of employees of each industrial sector /the total number of employees of industrial sectors
Industrial structure (*stru*)	the output value of each industrial sector /the total output value of all industries

3.3. Data Sources

This paper selects China's 35 industrial sectors from the years 2006 to 2014. All the data has come from the corresponding year of the China Statistical Yearbook [27], China Industry Statistical Yearbook [28], China Statistical Yearbook on Science and Technology [29], China Energy Statistical Yearbook [30] and China Statistical Yearbook on Environment [31].

We then assign a serial number for each sector for convenience of discussion. The 35 industrial sectors are numbered in the following order in Table 3: S1–S5 are mining industries; S6–S32 belong to manufacturing industries; and S33–S35 are production and distribution of electricity, gas and water industries.

Table 3. Sector Classification.

Sectoral Code	Sector	Sectoral Code	Sector
S1	mining and washing of coal	S19	raw chemical materials and chemical products
S2	petroleum and natural gas extraction	S20	medical and pharmaceutical products
S3	ferrous metals mining and dressing	S21	chemical fiber
S4	nonferrous metals mining and dressing	S22	manufacture of rubber and plastic
S5	nonmetal minerals mining and dressing	S23	nonmetal mineral products
S6	processing of food from agricultural products	S24	smelting and pressing of ferrous metals
S7	food production	S25	smelting and pressing of nonferrous
S8	wine, beverage and refined tea production	S26	metal products
S9	manufacture of tobacco	S27	manufacture of general purpose machinery
S10	textile industry	S28	equipment for special purposes

Table 3. *Cont.*

Sectoral Code	Sector	Sectoral Code	Sector
S11	manufacture of textile wearing apparel, footwear and caps	S29	transport equipment
S12	manufacture of leather, fur, feather and its products	S30	electric equipment and machinery
S13	processing of timbers, manufacture of wood, bamboo, rattan, palm and straw products	S31	manufacture of communication equipment, computer and other electronic equipment
S14	furniture manufacturing	S32	measuring instrument, cultural and office machinery
S15	papermaking and paper products	S33	production and supply of electric power and heat power
S16	printing and record medium reproduction	S34	production and distribution of gas
S17	culture, educational, art and sports goods	S35	production and distribution of water
S18	processing of petroleum, coking, processing of nucleus fuel		

4. Typical Fact and Research Hypotheses

4.1. Changing Trend Analysis of Environmental Regulation and Carbon Productivity

At present, academia has not yet reached consensus on the impact of environmental regulation on carbon productivity. Some argue that regulation actions regarding CO_2 emission reduction facilitate long-term environmental performance [32,33]. On the contrary, others found that the regulation costs lead to productivity loss. Regulatory effects caused a slight decrease in the overall productivity for the European commercial transport industry from 1995 to 2006 [34]. In order to more explicitly conduct the analysis, we depict the scatter plot that indicates the relationship between environmental regulation and carbon productivity. As is shown in Figure 2, the linear fitted values display a negative relationship between the two variables.

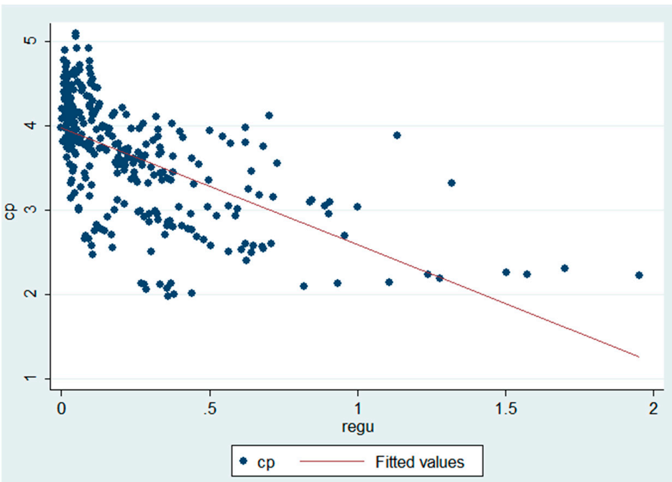


Figure 2. Relationship between environmental regulation and carbon productivity.

4.2. Changing Trend Analysis of Technical Progress and Carbon Productivity

Current energy utilization rates could be improved through technological innovation, especially for those industries with high CO_2 emission levels. In general, enforcing innovation-oriented development strategies can accelerate the pace of technical progress. By utilizing high-end technology and advanced applicative knowledge to reform and upgrade traditional industries, these moves cannot only reduce energy consumption, decrease pollution and CO_2 emissions but also transform the development mode of over fuel combustion and environmental contamination; as well as enhancing industrial competitiveness to nurture new economic growth pole. The overall low carbon productivity of China's sub-industrial sectors is primarily due to the low efficiency of technology and scale [35]. Technical efficiency enhancement associated with CO_2 emissions is the contributor to an increase in environmental performance [36]. As is shown in the scatter plot, technical progress positively relates to carbon productivity (Figure 3).

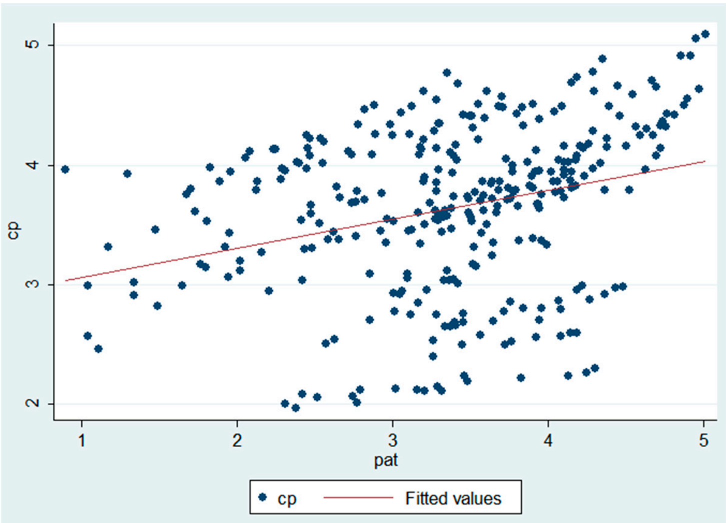


Figure 3. Relationship between technical progress and carbon productivity.

4.3. Research Hypotheses

Through the above typical facts analysis, this paper thus proposes the following research hypotheses:

H1: Environmental regulation level is negatively related to overall industrial carbon productivity. Due to inefficiency of environmental regulation and extra management cost for production units that resulted from regulation, industrial carbon performance will be hampered rather than promoted.

H2: Technical progress level is positively related to overall industrial carbon productivity. This indicates that more patent applications lead to a higher level of innovation and ultimately benefits carbon productivity for the corresponding industrial sector.

H3: The impact of environmental regulation and technical progress on carbon productivity is industrial sector-specific. That is to say, due to industrial heterogeneity, the impact varies by classifying industrial sectors into 3 types (capital and technology intensive, resource intensive, labor intensive) according to factor intensiveness.

5. Empirical Results

Before regression, we examined the VIF (Variance Inflation Factor) value of each explanatory variable. As is shown in Table 4, all the values range from 1.05 to 3.53, indicating that multicolinearity is not serious amongst the variables we selected. This is also supported in correlation coefficient matrix in Table 5. Descriptive statistics of all the variables are listed in Table 6.

Table 4. VIF Value of Each Explanatory Variable.

Dependent Variable: *cp*	VIF	1/VIF
regu	1.31	0.761842
pat	2.1	0.475452
fdi	1.05	0.949457
ecs	1.16	0.860189
ind	3.53	0.283286
stru	3.35	0.298904
Mean VIF	2.08	

Table 5. Correlation Coefficient Matrix.

	cp	*regu*	*pat*	*fdi*	*ecs*	*ind*	*stru*
cp	1						
regu	−0.6031	1					
pat	0.2957	-0.1687	1				
fdi	0.2684	−0.1212	−0.0496	1			
ecs	−0.1255	0.151	−0.1615	0.0454	1		
ind	0.1344	−0.1303	0.6949	0.0131	−0.0491	1	
stru	−0.1673	0.1398	0.6152	−0.1281	−0.2003	0.7629	1

Table 6. Descriptive Statistics of Main Variables.

Variable	Description	Unit	Obs	Mean	Standard Deviation	Min	Max
ln*cp*	natural logarithm of carbon productivity	-	315	3.6369	0.6902	1.9688	5.0966
regu	environmental regulation intensity	%	315	0.2429	0.2995	0.0001	1.9526
pat	natural logarithm of the numbers of patent application	-	315	3.3729	0.8382	0.9031	5.015
fdi	FDI inflow	%	315	5.0083	4.2171	0.0061	36.1881
ecs	energy consumption structure	%	315	67.636	23.8102	3.7614	98.1196
ind	industrialization level	%	315	0.3361	0.2585	0.0194	1.1735
stru	industrial structure	%	315	2.8467	2.383	0.1395	10.4481

Furthermore, the graph of kernel density estimation (Figure 4) displays that industrial-level carbon productivity has progressively changed from convergent shape to a dispersed pattern when the time interval is set at every four years. The overall carbon productivity level also has improved from the first year of 2006 to the last year of 2014, as the natural logarithmic peak value climbed from approximately 3.8 to 4.2.

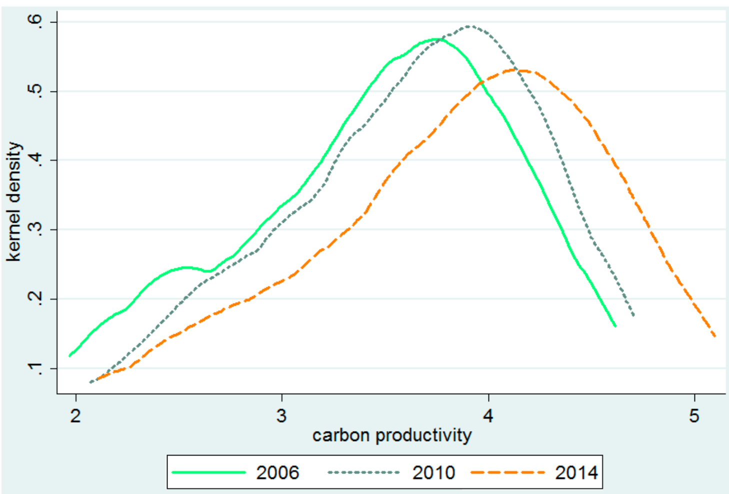


Figure 4. Kernel density estimation.

5.1. Estimation Results of Full Sample

Table 7 reports the estimation results of the full sample. Model (1) is the regression without any control variables; and only considering the two core explanatory variables of environmental regulation and technical progress. From which we can obviously see that the estimation coefficient of environmental regulation is significantly negative at 10% significance level and the estimation coefficient of technical progress is significantly positive at 1% significance level. This implies that environmental regulation and technical progress have respectively negative and positive relationships with carbon productivity. Models (2)–(5) are estimation results through stepwise incorporating of control variables. From the results we see that the two core independent variables are still statistically significant and the coefficient signs are consistent with Model (1). For the control variables, FDI, industrialization levels and industrial structure are significant at 1%, 5% and 15% level, respectively; while the energy consumption structure is not significant. Research hypotheses of 1 and 2 (H1, H2) have thus been verified.

Table 7. Estimation Results of Full Sample.

Explanatory Variables	(1) ln*cp*	(2) ln*cp*	(3) ln*cp*	(4) ln*cp*	(5) ln*cp*
regu	−0.0852 * (−1.84)	−0.0787 * (−1.72)	−0.0858 * (−1.87)	−0.0861 * (−1.88)	−0.0806 * (−1.70)
pat	0.2705 *** (17.95)	0.2526 *** (15.54)	0.2567 *** (15.59)	0.2425 *** (13.62)	0.2431 *** (13.59)
fdi		−0.0082 *** (−2.75)	−0.0084 *** (−2.82)	−0.0081 *** (−2.71)	−0.0081 *** (−2.68)
ecs			−0.0011 (−1.44)	−0.0011 (−1.45)	0.2389 (−1.39)
ind				0.2463 ** (2.04)	0.2389 ** (1.96)
stru					0.0083 # (0.47)
_cons	2.7451 *** (49.91)	2.8454 *** (43.45)	2.9146 *** (35.94)	2.8779 *** (34.83)	2.8503 *** (28.11)
R^2	0.1259	0.0932	0.0994	0.0868	0.0708
F-statistic	182.28 [0.00]	126.90 [0.00]	96.07 [0.00]	78.56 [0.00]	65.32 [0.00]
Hausman Test	10.80 [0.00]	12.36 [0.00]	15.29 [0.00]	11.38 [0.04]	18.98 [0.00]
model	FE	FE	FE	FE	FE
obs	315	315	315	315	315

Note: the value in the parenthesis is *t*-statistic or *z*-statistic; #, *, **, *** denote 15%, 10%, 5% and 1% significance level, respectively.

5.2. Estimation Results of Subgroups

To further investigate the impact of China's industrial environmental regulation and technical progress on carbon productivity, we subdivided the 35 industrial sectors into capital and technology intensive, resource intensive and labor intensive types according to factor intensiveness. Capital and technology intensive type including 13 sub-industrial sectors (S17, S19–S22, S24, S25, S27–S32) and resource intensive (S1, S2, S6–S9, S13, S18, S33–S35) and labor intensive type both consist of 11 sub-industrial sectors (S3–S5, S10–S12, S14–S16, S23, S26).

Table 8 reports the estimation results of the subgroups. Models (2), (4) and (6) are the complete estimation results of the subgroups. From Models (2) and (4) we can see that environmental regulations exert a insignificant positive and negative effect on carbon productivity for the capital and technology intensive industry and the resource intensive industry, respectively. Model (6) reveals that the environmental regulation constantly negatively influences carbon productivity for the labor intensive industry. It is worthwhile noting that for all the models, technical progress plays an important role in enhancing carbon productivity for all types of industrial sectors and the significance test has been passed at 1% level. Hence, research hypothesis 3 (H3) can be confirmed.

Table 8. Estimation Results of Subgroups.

Explanatory Variables	(1) K-T	(2) K-T	(3) Res	(4) Res	(5) L	(6) L
regu	0.0743	0.1025	−0.1065 *	−0.0699	−0.1696 ***	−0.1382 **
	(0.36)	(0.47)	(−1.68)	(−1.04)	(−2.82)	(−2.39)
pat	0.2809 ***	0.2797 ***	0.1456 ***	0.1601 ***	0.1390 ***	0.1448 ***
	(7.44)	(7.27)	(5.09)	(4.72)	(4.38)	(4.65)
fdi		−0.0007	−0.0501 ***	−0.0496 ***	−0.0367 ***	−0.0431 ***
		(−0.20)	(−5.83)	(−5.72)	(−4.48)	(−5.23)
ecs	0.0004	0.0005	−0.0118 ***	−0.0113 ***		−0.0022
	(0.46)	(0.51)	(−6.16)	(−5.79)		(−1.40)
ind	0.2884 *	0.2998 *		−0.3456		−0.4839 #
	(1.81)	(1.83)		(−0.69)		(−1.46)
stru		0.0107		0.0623 #	−0.0134	0.0774 #
		(0.44)		(1.48)	(−0.42)	(1.48)
_cons	2.5230 ***	2.4729 ***	4.0078 ***	3.8512 ***	3.5804 ***	3.7394 ***
	(18.79)	(12.53)	(20.12)	(17.32)	(20.08)	(19.74)
R^2	0.2077	0.1461	0.0685	0.1143	0.0960	0.0286
F-statistic or Wald	38.45 [0.00]	25.22 [0.00]	50.64 [0.00]	34.35 [0.00]	203.00 [0.00]	41.20 [0.00]
Hausman Test	349.88 [0.00]	114.04 [0.00]	14.94 [0.00]	57.18 [0.00]	1.38 [0.85]	30.02 [0.00]
model	FE	FE	FE	FE	RE	FE
obs	117	117	99	99	99	99

Note: the value in the parenthesis is *t*-statistic or *z*-statistic; #, *, **, *** denote 15%, 10%, 5% and 1% significance level, respectively.

5.3. Endogeneity Problem

In view of the above-mentioned estimation results that the impact varies among the different factor intensive industries, we deduce that part of the reason is industrial heterogeneity; the other may be an endogeneity problem. Endogeneity is confirmed through Block Exogeneity Wald test in Table 9. In general, the way to solve endogeneity problem is to employ the instrumental variable method. However, it is difficult to find the most suitable instrumental variables. The common practice is to take endogeneous variables' or other variables' lagged terms as instrumental variables. By using this idea as a preference, this paper selects the first and second period lagged terms of endogeneous variables of environmental regulation and technical progress as instrumental variables in order to tackle the endogeneity problem. Also, using Anderson Canon LM statistic to test the under-identification problem of instrumental variables; using Cragg-Donald Wald F value to test the weak instrumental variables problem, that is to say, the null hypothesis of instrumental variables are not relevant to endogeneous variables; using Sargan statistic to test the over-identification problem of instrumental variables.

Table 9. Block exogeneity wald test.

Dependent Variable: *cp*			
Excluded	**Chi-sq**	**df**	**Prob.**
regu	4.646303	2	0.098
pat	8.47996	2	0.0144
fdi	0.312423	2	0.8554
ecs	3.421889	2	0.1807
ind	2.689937	2	0.2605
stru	0.093402	2	0.9544
All	23.83384	12	0.0214

Table 10 reports the estimation results of IV-2SLS for full sample, capital and technology intensive sectors, resource intensive sectors and labor intensive sectors, respectively. Model (1) demonstrates that after taking into consideration of endogeneity of variables, the coefficients of environmental regulation and technical progress are both significant at 1% level. The absolute values of estimated coefficient are also larger than those without consideration of endogeneity, which indicates that the influence of environmental regulation and technical progress on carbon productivity is consistent and robust. FDI and industrialization levels have significant positive effects on carbon productivity at the 1% and 10% level, respectively. Industrial structure significantly, negatively affects carbon productivity, while energy consumption structure's negative influence on carbon productivity is insignificant.

Table 10. Estimation results of IV-2SLS.

Explanatory Variables	(1) All	(2) K-T	(3) Res	(4) L
regu	−1.0987 *** (−8.67)	−1.7628 *** (−4.94)	−1.0505 *** (−5.9)	0.4319 ** (1.96)
pat	0.3671 *** (6.11)	0.6099 *** (3.98)	0.5893 *** (4.82)	0.7345 *** (8.39)
fdi	0.0262 *** (3.60)	0.0130 (1.38)	0.0346 ** (2.30)	−0.0592 *** (−4.58)
ecs	−0.0019 (−1.43)	0.0005 (0.30)	0.0086 *** (3.75)	−0.0162 *** (−8.06)
ind	0.4085 * (1.81)	0.3656 (0.93)	−1.5465 *** (−3.51)	2.6057 *** (8.60)
stru	−0.1424 *** (−5.58)	−0.0849 ** (−2.26)	−0.0832 * (−1.67)	−0.7354 *** (−11.35)
_cons	2.9052 *** (13.80)	1.6734 *** (2.69)	1.5877 *** (4.15)	3.1889 *** (−14.40)
R^2	0.5524	0.7706	0.6204	0.8513
F-statistic	49.00 [0.00]	46.59 [0.00]	19.18 [0.00]	68.51 [0.00]
Anderson Canon LM	193.85 [0.00]	60.65 [0.00]	63.58 [0.00]	28.45 [0.00]
Cragg-Donald Wald F	223.57 [7.56]	40.96 [7.56]	80.52 [7.56]	9.96 [7.56]
Sargan	0.03 [0.98]	0.56 [0.76]	2.56 [0.28]	0.38 [0.82]
obs	245	91	77	77

Note: the value in the parenthesis is t-statistic or z-statistic; *, **, *** denote 10%, 5% and 1% significance level, respectively.

The above regression results show that from the perspective of whole industrial sectors, raising the utilization level of FDI and promoting the industrialization process are beneficial for enhancement of carbon productivity. Model (2) reports the estimation result of capital and technology intensive sectors. The two core independent variables are significant; but in comparison to the FE estimation method, the significance level of environmental regulation has been improved. We can draw the conclusion that environmental regulation actions do indeed impact greatly on the output efficiency of the capital and technology intensive sectors, as the driving force of technical progress is no longer the main contributor to the further improvement of carbon productivity. The implementation of harsh environmental regulation hinders carbon productivity. All control variables are not significant except for in the industrial structure, which has a negative impact at 5% significance level. For resource intensive sectors in Model (3), the impact intensity of environmental regulation and technical progress is in the middle compared to that of capital and technology intensive sectors and labor intensive sectors. All of the control variables are showing significant effects. Introduction of FDI inflow and current energy consumption structure can boost carbon productivity. For labor intensive sectors in Model (4), the significance level of technical progress is higher than that of environmental regulation, indicating that technological innovation plays a more influential role in impacting carbon productivity. Given that labor intensive sectors, including such as mining and dressing, textile industry, furniture manufacturing, papermaking and paper products, printing and record medium reproduction, are of low technological content; technical factor is the main driving force for those sectors that are highly dependent on input of a cheap labor factor. Control variables of FDI, energy consumption and industrial structure impede improvement in carbon productivity, whereas industrialization level exerts a positive influence on carbon productivity that is significant at 1% level.

6. Conclusions and Policy Implications

Using China's 35 industrial sectors panel data from 2006 to 2014, this research explores the impact of environmental regulation and technical progress on carbon productivity. The following conclusions have been reached based on empirical analysis. Environmental regulation and technical progress, respectively, exert a significant negative and positive effect on carbon productivity. Inconsistency and inefficiency of current regulation actions are considered to be the main reason for this negative effect, which is contrary to expectations. After grouping according to factor intensiveness, capital and technology intensive sectors are more greatly influenced by environmental regulation; by comparison, labor intensive sectors are affected by technical progress to a larger extent; the impact range of environmental regulation and technical progress on resource intensive sectors, which feature heavy and chemical industry, is in the middle. On the whole, the industrial structure is unfavorable to carbon productivity improvement. Capital and technology intensive sectors should pay more attention to the optimization of the industrial structure; FDI and energy consumption structures are beneficial in enhancing carbon productivity for resource intensive sectors; and the industrialization level should be promoted in order for the labor intensive sectors to raise their carbon productivity. Based upon the above analysis, we can get the following industrial sector-specific policy implications:

Firstly, for capital and technology intensive sectors, industrial development should be innovation-driven and supported by government, and allow further optimization of the industrial structure. Importance should be attached to readjusting the industrial internal structure to eliminate backward production capacity. Also, government should spare no effort in encouraging non-state-owned economies to develop high-tech industries and strategic emerging industries.

Secondly, for resource intensive sectors, the energy consumption structure should be readjusted and the utilization efficiency of FDI should be raised. To reduce CO_2 emissions volume and boost carbon productivity, renewable and low-carbon energies including wind power, solar power and bio-energy should be explored. Government should adopt approaches to lowering the proportion of coal in energy consumption and enhancing technological research and development. In addition: government should raise public awareness by raising the profile of energy and resource saving through extensive publicity; the gradual creation of the positive implications of low-carbon energy consumption; and progressively establishing a complete clean energy consumption system.

Thirdly, for labor intensive sectors, environmental regulations should be continuously strengthened to improve their effect and to improve technical innovation and industrialization levels. The number of employees account for a large proportion when compared to other types of industries, indicating that the production process is characterized by manual work, such as textile and apparel industries. Automation should be promoted to replace the products and processing that is most reliant on manual labor, as much as possible and producing technologically high value-added goods via technical upgrading and reconstruction.

Overall, it has been proven to be true that institution and technology are the two main driving forces for maintaining economic growth in the middle to long term. Thus, environmental regulation and patent applications are the most influential factors. Policy makers should focus on the key fields that relate to long-term development and establish technical objectives to improve core competency comprehensively. Furthermore, communication should be encouraged amongst the industries in order to positively share learned experiences to sustain further improvement.

Acknowledgments: The authors are grateful to three anonymous reviewers for their helpful feedback and comments. The research is supported by the National Social Science Foundation of China (No. 09AZD047).

Author Contributions: In this paper, Huan Zhang conceived and designed the framework, collected the data, wrote and revised the paper. Kangning Xu helped with the data collection and paper revision.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Kaya, Y.; Yokobori, K. *Environment, Energy and Economy: Strategies for Sustainability*; United Nations University Press: Tokyo, Japan, 1997.
2. Beinhocker, E.; Oppenheim, J. *The Carbon Productivity Challenge: Curbing Climate Change and Sustaining Economic Growth*; McKinsey Global Institute: Chicago, IL, USA, 2008.
3. Zaim, O.; Taskin, F. Environmental efficiency in carbon dioxide emissions in the OECD: A non-parametric approach. *J. Environ. Manag.* **2000**, *58*, 95–107. [CrossRef]
4. Meng, M.; Niu, D.X.; Gao, Q. Decomposition Analysis of Chinese Provincial Economic Growth through Carbon Productivity Analysis. *Environ. Prog. Sustain. Energy* **2014**, *33*, 250–255. [CrossRef]

5. Azomahou, T.; Laisney, F.; Van, P.N. Economic development and CO_2 emissions: A nonparametric panel approach. *J. Public Econ.* **2006**, *90*, 1347–1363. [CrossRef]
6. Davidsdottir, B.; Fisher, M. The odd couple: The relationship between state economic performance and carbon emissions economic intensity. *Energy Policy* **2011**, *39*, 4551–4562. [CrossRef]
7. Zhou, P.; Ang, B.W.; Han, J.Y. Total factor carbon emission performance: A Malmquist index analysis. *Energy Econ.* **2010**, *32*, 194–201. [CrossRef]
8. Zhou, G.H.; Chung, W.; Zhang, X.L. A study of carbon dioxide emissions performance of China's transport sector. *Energy* **2013**, *50*, 302–314. [CrossRef]
9. Zhang, N.; Wei, X. Dynamic total factor carbon emissions performance changes in the Chinese transportation industry. *Appl. Energy* **2015**, *146*, 409–420. [CrossRef]
10. Zhang, N.; Zhou, P.; Kung, C.C. Total-factor carbon emission performance of the Chinese transportation industry: A bootstrapped non-radial Malmquist index analysis. *Renew. Sustain. Energy Rev.* **2015**, *41*, 584–593. [CrossRef]
11. Hu, X.C.; Liu, C.L. Carbon productivity: A case study in the Australian construction industry. *J. Clean. Prod.* **2016**, *112*, 2354–2362. [CrossRef]
12. Sun, M.X.; Yuan, Y.; Zhang, J.Y.; Wang, R.Q.; Wang, Y.T. Greenhouse gas emissions estimation and ways to mitigate emissions in the Yellow River Delta High-efficient Eco-economic Zone, China. *J. Clean. Prod.* **2014**, *81*, 89–102. [CrossRef]
13. Shao, C.F.; Guan, Y.; Wan, Z.; Guo, C.X.; Chu, C.L.; Ju, M.T. Performance and decomposition analyses of carbon emissions from industrial energy consumption in Tianjin, China. *J. Clean. Prod.* **2014**, *64*, 590–601. [CrossRef]
14. Kortelainen, M. Dynamic environmental performance analysis: A Malmquist index approach. *Ecol. Econ.* **2008**, *64*, 701–715. [CrossRef]
15. Meng, M.; Niu, D.X. Three-dimensional decomposition models for carbon productivity. *Energy* **2012**, *46*, 179–187. [CrossRef]
16. Chang, Y.F.; Lin, S.J. Structural decomposition of industrial CO_2 emission in Taiwan: An input-output approach. *Energy Policy* **1998**, *26*, 5–12. [CrossRef]
17. He, J.K.; Deng, J.; Su, M.S. CO_2 emission from China's energy sector and strategy for its control. *Energy* **2010**, *35*, 4494–4498. [CrossRef]
18. Guo, W.; Sun, T.; Dai, H.J. Effect of Population Structure Change on Carbon Emission in China. *Sustainability* **2016**, *8*, 225. [CrossRef]
19. Long, R.Y.; Shao, T.X.; Chen, H. Spatial econometric analysis of China's province-level industrial carbon productivity and its influencing factors. *Appl. Energy* **2016**, *166*, 210–219. [CrossRef]
20. Kaya, Y. *Impact of Carbon Dioxide Emission on GNP Growth: Interpretation of Proposed Scenarios*; IPCC: Paris, France, 1989.
21. York, R.; Rosa, E.A.; Dietz, T. STIRPAT, IPAT and ImPACT: Analytic tools for unpacking the driving forces of environmental impacts. *Ecol. Econ.* **2003**, *46*, 351–365. [CrossRef]
22. IPCC. *Intergovernmental Panel on Climate Change (IPCC) Climate Change 2007: The Fourth Assessment Report of the Intergovernmental Panel on Climate Change*; Cambridge University Press: Cambridge, UK, 2007.
23. Apergis, N.; Ozturk, I. Testing Environmental Kuznets Curve hypothesis in Asian countries. *Ecol. Indic.* **2015**, *5*, 16–22. [CrossRef]
24. Cole, M.A.; Elliott, R.J.R. Determining the trade-environment composition effect: The role of capital, labor and environmental regulations. *J. Environ. Econ. Manag.* **2003**, *46*, 363–383. [CrossRef]
25. Mani, M.; Wheeler, D. In Search of Pollution Havens? Dirty Industry in the World Economy, 1960 to 1995. *J. Environ. Dev.* **1998**, *7*, 215–247. [CrossRef]
26. Griliches, Z. Patent statistics as economic indicators: A survey. *J. Econ. Lit.* **1990**, *28*, 1661–1707.
27. National Bureau of Statistics of China. *China Statistical Yearbook, 2007–2015*; China Statistics Press: Beijing, China, 2007–2015. (In Chinese)
28. National Bureau of Statistics of China. *China Industry Statistical Yearbook, 2007–2015*; China Statistics Press: Beijing, China, 2007–2015. (In Chinese)
29. National Bureau of Statistics of China. *China Statistical Yearbook on Science and Technology, 2007–2015*; China Statistics Press: Beijing, China, 2007–2015. (In Chinese)

30. National Bureau of Statistics of China. *China Energy Statistical Yearbook, 2007–2015*; China Statistics Press: Beijing, China, 2007–2015. (In Chinese)
31. National Bureau of Statistics of China. *China Statistical Yearbook on Environment, 2007–2015*; China Statistics Press: Beijing, China, 2007–2015. (In Chinese)
32. Wang, Q.W.; Zhou, P.; Shen, N.; Wang, S.S. Measuring carbon dioxide emission performance in Chinese provinces: A parametric approach. *Renew. Sustain. Energy Rev.* **2013**, *21*, 324–330. [CrossRef]
33. Wang, K.; Wei, Y.M. Sources of energy productivity change in China during 1997–2012: A decomposition analysis based on the Luenberger productivity indicator. *Energy Econ.* **2016**, *54*, 50–59. [CrossRef]
34. Krautzberger, L.; Wetzel, H. Transport and CO_2: Productivity Growth and Carbon Dioxide Emissions in the European Commercial Transport Industry. *Environ. Res. Econ.* **2012**, *53*, 435–454. [CrossRef]
35. Gao, W.J.; Zhao, G.H. The analysis of the Generalized Carbon-productivity in China's Sub-Industrial sectors. In *Renewable and Sustainable Energy, Pts 1–7*; Pan, W., Ren, J.X., Li, Y.G., Eds.; Trans Tech Publications Ltd.: Stafa-Zurich, Switzerland, 2012; Volume 347–353, pp. 1326–1330.
36. Tan, Q.L.; Zhang, X.P.; Wei, Y.M. Exploring the changes of carbon emissions performance using data envelopment analysis. In *Advances in Energy Science and Technology, Pts 1–4*; Tang, X., Chen, X., Dong, Y., Wei, X., Yang, Q., Eds.; Trans Tech Publications Ltd.: Stafa-Zurich, Switzerland, 2013; Volume 291–294, pp. 1433–1438.