Journal of Cleaner Production 179 (2018) 325–334

Contents lists available at ScienceDirect

Journal of Cleaner Production

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

The effects of environmental regulation on China's total factor productivity: An empirical study of carbon-intensive industries

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ARTICLE INFO

Article history:
Received 20 July 2017
Received in revised form
28 November 2017
Accepted 13 January 2018
Available online 16 January 2018

Keywords:
Environmental regulation
Total factor productivity
Strong Porter-hypothesis
Carbon-intensive industries

ABSTRACT

In this paper, we first identify China's carbon-intensive industries (CIIs) by constructing a carbon intensive index taking both the scale and intensity of CO_2 emission into account. Then the strong version of Porter Hypothesis (PH), i.e., the positive effect of environmental regulation on total factor productivity (TFP) of China's CIIs is tested. In order to overcome the endogenous issue of model specification, two-stage least squares (2SLS) method is employed. The results indicate that there is a significant inverted U-shape relationship between environmental regulation intensity and the TFP of China's CIIs, demonstrating the inexistence of strong PH effect in a long run, and the impact of environmental regulation on CIIs is changing gradually from innovation offsets to compliance costs. In addition, optimal environmental regulation intensities for different CIIs are also studied according to their locations on the inverted U-shaped curve: the Production and Supply of Electric Power and Heat Power Industry has exceeded the optimal environmental regulation intensity, while the remaining CIIs have not reached their inflection points. Therefore, specific policy proposals should be formulated according to the different stages of environmental regulation in various industries.

1. Introduction

Serving as the mainstay of national economy, the carbon-intensive industries in China emit nearly 80% of the total CO_2 emissions in 2010 (Yuan and Zhao, 2016). In order to fulfill the "Intended Nationally Determined Contribution" submitted to the United Nations in June 2015 stating that China's total CO_2 emissions would peak around 2030 or even earlier, and its carbon emission intensity would decrease by 60–65% compared with 2005 (Liu et al., 2017), the central government has attached more importance to the industries with both large scale and high intensity of CO_2 emissions when formulating and carrying out its current environmental regulations. In this context, the following two issues arise: (i) what are the impacts of China's environmental regulations have imposed on the TFP of the carbon-intensive industries (CIIs) over the past decade? Is it serving as a roll booster or a stumbling block? (ii) Given the obvious heterogeneity in terms of technological level and development phases among the CIIs, one-size-fits-all environmental regulation may bring about very different impacts; so what are the optimal environmental regulation intensities for each CII?

The standard neoclassical paradigm holds that strict environmental regulation will exacerbate the competitiveness and productivity by constraining industry behavior (Denison, 1981; Gollop and Roberts, 1983). At the end of the twentieth century, Michael Porter (1991) and Porter and Van Der Linde (1995) challenged this view and proposed the "Porter Hypothesis" (PH), which argued that more stringent but properly designed environmental regulation can trigger innovation that may offset compliance costs and enhance firm's productivity. Jaffe and Palmer (1997) were the first to classify the PH effects into three categories: (1) the weak PH stating that properly designed environmental regulation may lead to innovation, though it is not known whether the innovation is good or bad for firms; (2) the strong PH stating that in most cases, environmental regulation can not only offset the costs of compliance, but also improve the competitiveness of firms; (3) the narrow PH arguing that flexible

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https://doi.org/10.1016/j.jclepro.2018.01.100
0959-6526/

regulatory policies are more likely to increase firm's incentives to innovate than prescriptive forms of regulation.

The formation mechanism of PH is illustrated in Fig. 1. When there was no environmental regulation, firms seek to maximize their economic profits without considering the pollutant discharge costs. After environmental regulation policies are implemented by the government, the costs for pollutant emissions reduction will increase significantly (Denison, 1981; Gollop and Roberts, 1983), which would compel firms to engage in environment-friendly innovation (Porter and Van Der Linde, 1995; Rubashkina et al., 2015). Technological innovations for emissions reduction increase the operating cost of firm inevitably, but it reduces the pollution emission cost conversely. As the environmental regulation becomes more and more stringent, the compliance cost may rise, while the innovation offsets raise faster (Porter and Van Der Linde, 1995; Lanoie et al., 2008). Therefore, the impacts of environmental regulations on business costs could be positive or negative, resulting in a non-linear relationship between environmental regulation and firms' total factor productivity.

Up to now, scholars such as Brunnermeier and Cohen (2003), Zhao and Sun (2016), Lanoie et al. (2011) and Rubashkina et al. (2015) have reached relatively consistent conclusions on the existence of weak and narrow versions of Porter-hypothesis, that is, environmental regulation is positively related to enterprise innovation. In contrast, there is not a consistency on the existence of strong PH. Denison (1981), Gray and Shadbegian (1995) concluded that environmental regulation policy has led to a reduction in productivity. On the contrary, Hamamoto (2006) found that environmental regulations have led to an increase in innovation (R&D spending) and productivity of five Japanese manufacturing sectors in the 1960s and 1970s. Yang et al. (2012), Jorge et al. (2015) and Qiu et al. (2017) insisted the positive effects of environmental regulation tightening on productivity. The discrepancy between the results of different scholars is caused by the fact that there is no uniform standard on the measurement of environmental regulation intensity (Albrizio et al., 2017). In fact, the impact of environmental regulation on TFP depends on the predominance of the positive "innovation offsets" effect and the negative "compliance costs" effect, and so more recent studies have therefore focused on the non-linear relationship between environmental regulation and TFP (Li and Tao, 2012; Yuan et al., 2017; Johnstone et al., 2017; Albrizio et al., 2017).

In domestic, the initial researches focused on weak version of Potter-hypothesis testing and most studies supported the existence of weak PH (Xu et al., 1995; Jiang et al., 2013). With the rapid development of Chinese economy and the worsening environment, there has been an increasing interest in strong PH testing. Relevant research literature can be divided into two categories. On the one hand, some scholars have calculated China's green total factor productivity by taking pollutant emissions into consideration (Chen, 2010; Wang and Liu, 2015; Yang and Yang, 2016). On the other hand, the studies focused on the effect of environmental regulation on total factor productivity (Hu et al., 2017; Li and Wu, 2017). Most of them test strong PH based on regional perspective analysis while a few based on industry perspective analysis (Wang and Wang, 2011; Bi et al., 2014). What's more, there are few studies on high CO_2 emission industries, especially for CIIs.

CIIs are the main sources of China's total CO_2 emissions as well as the key areas targeted by environmental regulation of the central government. Therefore, it is of great significance to analyze the relationship between environmental regulation intensity and TFP for China's CIIs. At present, scholars have identified CIIs according to the scale, intensity, and leakage of carbon emissions (Farla et al., 1995; Chen, 2009; Fu and Zhang, 2014; Johan and Filip, 2015), but there is no uniform standard regarding the definition and measurement of CIIs. In this paper, we aim to define China's CIIs rationally and scientifically by constructing a carbon intensive index taking both the intensity and scale of CO_2 emissions into account. Subsequently, the strong Porter Hypothesis (PH) effect of China's CIIs is tested; in order to overcome the endogenous issue of model specification, two-stage least squares (2SLS) method is employed. At last, the optimal environmental regulation intensities for each CII are also studied.

The remainder of this paper is structured as follows: Section 2 defines the carbon-intensive industries (CIIs) by constructing a carbon intensive index; Section 3 describes the model specification, data source and variables; Section 4 presents the empirical results on the link between environmental regulation intensity and total factor productivity of CIIs, and plots the specific locations of current environmental regulation intensities for each CII on the inverted U-shaped curve; Section 5 concludes and puts forward some useful policy recommendations.

2. Identification of CIIs

2.1. Definition of CIIs

In general, CIIs refer to the sectors having a larger scale or higher intensity of CO_2 emission, or both, which lead to more intensive carbon emissions either directly or indirectly in production process if they were not well treated. Therefore, they should be defined from the perspectives of scale and intensity of industrial carbon emission. The scale of carbon emission is closely related to the total industrial output value and it does not reflect the carbon-intensive characteristic of the industry; similarly, the intensity of carbon emission does not reflect the impact of an industry on the environment as a whole. In this paper, we define China's CIIs by constructing a carbon intensive index taking both the scale and the

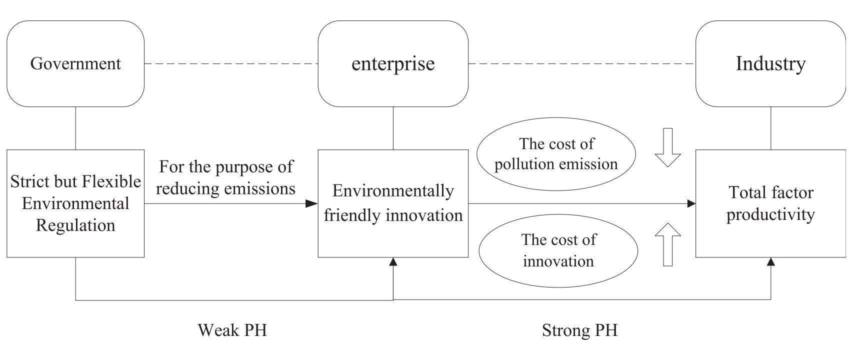

Fig. 1. The formation mechanism of Porter hypothesis.

intensity of CO_2 emission into account.

This paper selects 36 two-digital industries in China's industrial sector as the study sample. In current national industries classification, there are 41 two-digital industries. Since this classification had been revised and adjusted for three times since its first publication in 1984, four industries, i.e., Mining Support Activities for Mining, Other Manufacture, Utilization of Waste Resources, and Repair Service of Metal Product Machinery and Equipment, are excluded in order to maintain the coherence and consistency of data. Mining of Other Ores is also removed due to the lack of available statistical data. Before 2012, the Transportation Equipment Manufacturing Industry was split into the Manufacture of Automobiles, and Manufacture of Railway, Ship, Aerospace & Other Transportation Equipments in accordance with their average proportions over the past three years. The data for Rubber Products and Plastic Products Industries is added up and combined. Thus 36 industries are eventually selected.

The carbon emission for each industry is calculated by referring to the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* as follows,

$$CO_2 = \sum E_m \times NCV_m \times CEF_m \times COF_m \times \frac{44}{12}(m = 1, 2 \ldots 7) \qquad (1)$$

E_m represents the physical consumption of the m^{th} type of fuel; NCV_m represents its average low calorific value; CEF_m represents its carbon emission coefficient (Default values of carbon content) of standard consumption quantity, and COF_m represents the corresponding carbon oxidation factor. The fuels mainly involve coal, coke, crude oil, gasoline, kerosene, diesel oil, fuel oil, natural gas, and electricity. As electricity consumption does not directly produce carbon dioxide, and most of the crude oil is used for oil refining and other processing and conversion, they are excluded from the list to avoid duplicate calculations.

The CO_2 emissions from electricity consumption for each industry are indirectly calculated by the following three steps: (1) the total CO_2 emissions of Production and Supply of Electric Power and Heat Power (PSEPHP) Industry are first calculated, written as Y; (2) according to the proportions of electricity consumed by PSEPHP and the rest 35 industries as a whole (for example, p:q), the CO_2 emissions from electricity consumption for PSEPHP can be expressed as $\frac{p}{p+q} \cdot Y$, while the CO_2 emissions from electricity consumption for the rest 35 industries can be expressed as $\frac{q}{p+q} \cdot Y$; (3) assuming that the share of electricity consumption for the ith industry to the total amount of the rest 35 industries is S_i ($\sum_{i=1}^{35} Si = 1$), the CO_2 emissions from electricity consumption for each industry (in the rest 35 industries) can be expressed as $\frac{q}{p+q} \cdot Y \cdot Si$.

By adding the direct CO_2 emission (from the consumption of 7 types of fuels) to the corresponding indirect CO_2 emission (from the consumption of electricity), the total CO_2 emission of each industry during 2000–2014 can be finally calculated.

The carbon emission scale of the i^{th} industry, denoted as P_i, is defined as the ratio of its carbon emission (C_i) to the total carbon emission of the whole industrial sector as shown in equation (2),

$$P_i = C_i/(C_1 + C_2 + \ldots C_i)(i = 1,\ 2,\ 3 \ldots 36) \qquad (2)$$

T_i represents the carbon emission intensity of the i^{th} industry, expressed by its carbon emission divided by its economic output. Due to data availability, industrial sales value (ISV) is selected as the representation of economic output, and which is converted with the year 2000 as the base period.

$$T_i = C_i/ISV_i\ (\ i = 1, 2, 3 \ldots 36\ ) \qquad (3)$$

Then the scales and intensities of carbon emission for the 36 industries are normalized in Eqs (4)–(5), where $\min(P_i)$ and $\max(P_i)$ represent the minimum and maximum industrial carbon emissions in the industrial sector, and $\min(T)$ and $\max(T_i)$ represent the minimum and maximum industrial carbon emission intensities, respectively.

$$P_i^{'} = [P_i - \min(P_i)]/\left[\max(P_i) - \min(P_i)\right. \qquad (4)$$

$$T_i^{'} = [T_i - \min(T_i)]/[\max(T_i) - \min(T_i)] \qquad (5)$$

$$CI_i = \sqrt{P_i^{'} \times T_i^{'}} \qquad (6)$$

CI_i in Eq (6) is the carbon intensive index for the i^{th} industry. The larger CI_i is, the more intensive of carbon emission of the industry becomes.

Based on Eqs (4)–(6), the carbon intensive index for all the 36 two-digital industries is calculated, and the results are reported in Appendix A.[1] According to the carbon intensive index of each industry, seven carbon intensive industries including Smelting and Pressing of Ferrous Metals (SPFM), Manufacture of Non-metallic Mineral Products (MNMP), Manufacture of Raw Chemical Materials and Chemical Products (MRCMCP), Mining and Washing Coal (MWC), Smelting and Pressing of Non-ferrous Metals (SPNM), Processing of Petroleum, Coking and Processing of Nuclear Fuel (PPCPNF), and Production and Supply of Electric Power and Heat Power (PSEPHP) are chosen as the CIIs in this paper. It can be observed from Table 1 that the CO_2 emissions of CIIs account for 77.22% of the entire industrial sector. Moreover, the SPFM has the highest CO_2 emissions contributing to over 23% of the total.

The underlying reasons for this partition criterion are twofold. On the one hand, it can be observed that there is an obvious gap in carbon intensive index between the 7th industry (PSEPHP) and the 8th industry (MPPP). The carbon intensive index for PSEPHP is 0.29, nearly 1.7 times of that for MPPP. On the other hand, the total CO_2 emission for MPPP was 125 million tons in 2014, accounting for merely 2.01% of the entire industrial sector, thus it is not defined as a CII in current study. Compared with previous studies which divide the industrial sector into two equal parts according to the scale and/or the intensity of CO_2 emission (Chen, 2009; Fu and Zhang, 2014), this paper divides the industrial sector with a more convictive criterion.

Additionally, the variation trends of carbon intensive index for the 36 studied industries are also studied and the results are reported in Appendix B. For the seven CIIs, the changing processes of their carbon intensive index are shown in Fig. 2. First of all, the carbon intensive index of SPFM was persistently the highest over the whole study period. Second, the carbon intensive index for MNMP, MRCMCP and MWC are generally in the intermediate positions, although it underwent a violent fluctuation for MWC. At last, the carbon intensive index for the rest three CIIs, i.e., PSEPHP, PPCPNF, and SPNM, are overall the lowest.

2.2. Descriptive analysis of CIIs

The sales value and CO_2 emissions of the CIIs are shown in Fig. 3. From 2000 to 2014, the ratio of the sales value from CIIs to the total amount of the entire industrial sector increased at first and then failed, fluctuating around 40%. In contrast, the ratio of CIIs CO_2

[1] For the sake of saving space, only ten industries with the highest carbon intensive index are shown in Table 1.

Table 1
The rank of carbon intensive index for the top-ten industries.

Industry	Carbon emission (10^4 tons)	Scale of carbon emission	Sales value (10^4 RMB)	Carbon emission intensity (tons/RMB)	Carbon intensive index
SPFM	148051	23.84%	6366	22.31	0.970
MNMP	64481	10.38%	3608	17.87	0.566
MRCMCP	74853	12.05%	6498	11.52	0.504
MWC	44275	7.13%	2488	17.80	0.474
SPNM	39415	6.35%	3060	12.88	0.380
PPCPNF	60896	9.81%	8301	7.34	0.349
PSEPHP	47536	7.66%	7902	5.99	0.290
MPPP	12492	2.01%	1518	8.19	0.174
MMP	14308	2.30%	2627	5.41	0.161
MT	16050	2.58%	5115	3.10	0.117

Note: Calculated by the authors according to the data from “China Industry Statistical Yearbook,” “China Statistical Yearbook,” “China Statistical Yearbook on Environment,” “China Economic Census Yearbook 2004,” “China Environment Yearbook” and “China Statistical Yearbook on Environment”. MPPP represents the Manufacture of Paper and Paper Products Industry, MMP represents the Manufacture of Metal Products Industry, and MT presents the Manufacture of Textile Industry.

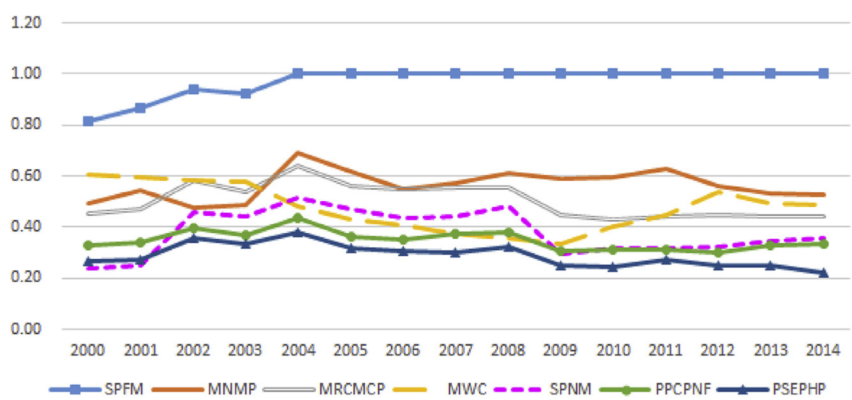

Fig. 2. The variation trends of carbon intensive index for CIIs.

emissions to that of the entire industrial sector has demonstrated a steady growth, which even reached up to 80% in 2014. As a result, it could be inferred that the negative effect of CIIs on the environment (carbon emissions) far outweighs their positive effect on the economy (sales value).

3. Model specification and data source

3.1. Model specification

The primary aim of this paper is to test the existence of strong PH effect for China's CIIs. To date, various methods have been developed to test the strong PH. First, previous studies specify the empirical models in log-log form and the estimated coefficients are interpreted as the elasticity of the environmental regulation intensity change to TFP growth (Yang et al., 2012; Rubashkina et al., 2015). Second, the threshold model is used to test the nonlinear relationship between environmental regulation and total factor productivity (Xie et al., 2017). Third, some studies introduce the square of the core explanatory variable to explore the nonlinear relationship between environmental regulation and TFP (Li and Tao, 2012).

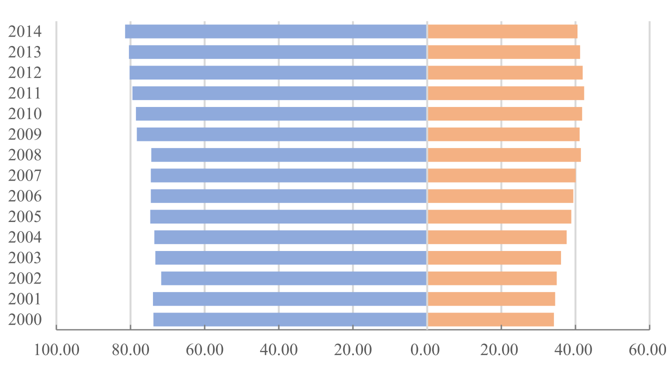

Fig. 3. Sales value and carbon emissions of CIIs (2000–2014).

In order to observe the changes of industrial total factor productivity as the intensity of environmental regulation increases, we choose the third way to test strong PH. In particular, the 2SLS model is employed to solve the endogenous problem of the model specification. If there was a U-shaped (inverted U-shaped) relationship between environmental regulation and industrial total factor productivity, the strong version of Porter hypothesis effect exists (not exists) in the long run. Moreover, the TFP index is further decomposed into two components including technical change and technical efficiency, i.e., TFP = TECH × EFCH, and the existence of U-shaped or inverted U-shaped relationships between environmental regulation and the two components are also studied. To this end, the regression models are specified as follows:

$$TFP_{i,t} = a_0 + a_1 ER_{i,t} + a_2 ER_{i,t}^2 + \delta X_{i,t} + V_t + \varepsilon_{i,t} \quad (7)$$

$$Effch_{i,t} = \beta_0 + \beta_1 ER_{i,t} + \beta_2 ER_{i,t}^2 + \delta X_{i,t} + V_t + \varepsilon_{i,t} \quad (8)$$

$$Techch_{i,t} = \gamma_0 + \gamma_1 ER_{i,t} + \gamma_2 ER_{i,t}^2 + \delta X_{i,t} + V_t + \varepsilon_{i,t} \quad (9)$$

$TFP_{i,t}$ is the total factor productivity of the ith industry in year t. Since the main purpose of this paper is to investigate the effect of environmental regulation on industrial TFP improvement rather than on its growth rate, $TFP_{i,t}$ is converted into the cumulative TFP index in year t following Kumar and Managi (2008) and Qiu et al. (2008). In the same way, technical efficiency ($Effch_{i,t}$) and technical change ($Techch_{i,t}$) are also converted into cumulative growth rates. $ER_{i,t}$ represents the intensity of environmental regulation of the ith industry in the tth year, and $ER_{i,t}^2$ represents the square of its environmental regulation. In addition, $X_{i,t}$, V_t and $\varepsilon_{i,t}$ represent the control variable, the year effect and the random disturbance, respectively.

3.2. Variable selections, data source and processing

3.2.1. TFP

Stochastic Frontier Analysis (SFA) and Data Envelopment Analysis (DEA) are currently two of the most conventional methods for industrial TFP measurement. In this paper, the DEA method is employed to evaluate the Malmquist productivity index of CIIs with its main advantage of no need to assume the specific form of the production function. Assuming that each carbon-intensive industry is a production decision-making unit, D_k^t is the output distance function of the kth industry in the tth stage, and D_k^{t+1} is the output distance function in the $t+1$st stage, where $k=7$ and $t=15$. M_k is the Malmquist index for the kth industry, which is expressed as follows:

$$M_k\left(x^{t+1},y^{t+1};x^t,y^t\right)=\left\{\left[\frac{D_k^t(x^t,y^t)}{D_k^t(x^{t+1},y^{t+1})}\right]\left[\frac{D_k^{t+1}(x^t,y^t)}{D_k^{t+1}(x^{t+1},y^{t+1})}\right]\right\}^{\frac{1}{2}} \quad (10)$$

$$M_k\left(x^{t+1},y^{t+1};x^t,y^t\right)=\frac{D_k^t(x^t,y^t)}{D_k^{t+1}(x^{t+1},y^{t+1})}\left[\frac{D_k^{t+1}(x^t,y^t)}{D_k^t(x^{t+1},y^{t+1})}\times\frac{D_k^{t+1}(x^t,y^t)}{D_k^t(x^t,y^t)}\right]^{\frac{1}{2}} \quad (11)$$

TFP measurement mainly involves the input indicators of capital and labor as well as an economic output indicator. At present, scholars generally use the "Perpetual Inventory Method" to calculate capital stock with the formula $K_{i,t}=I_{i,t}+(1-\delta_{i,t})K_{i,t-1}$. Since subdivided industrial data is difficult to obtain and the calculation of the net value of fixed assets is consistent with the Perpetual Inventory Method, this paper calculates the difference between the original value of fixed assets and the cumulative depreciation by referring to the approach from Dong et al. (2012). The net value of fixed assets is deflated to the constant price as of the year 2000 in accordance with the producer price index for industrial products.[2] The data is collected from *China Industry Statistical Yearbook*, *China Statistical Yearbook* and *China Economic Census Yearbook 2004*.

The number of employed person is used as labor input. The data on the number of employed person in the subdivided industries of China's industrial sector is not continuous. The labor data for the years 2003, 2005–2011 and 2013–2014 is obtained from *China Industry Statistical Yearbooks*, the data for 2004 comes from *China Statistical Yearbook 2005*, and the data for 2012 cannot be acquired directly and thus we obtain it by averaging based on the labor data of the preceding and succeeding years. The desirable output is generally represented by industrial added value. Due to the data missing after the year 2008, this paper employs the consecutive industrial sales values in the industrial sector at 2000 prices, and the original data is collected from *China Industry Statistical Yearbooks*.

3.2.2. Environmental regulation intensity

The environmental regulation intensity of CIIs mainly involves the cost of implementing the regulation, such as Pollution Abatement and Control Expenditure (PACE). Following Breman and Bui (2001), Cole and Elliott (2003), and Lanoie et al. (2011), this paper measures the intensity of Environmental Regulation (ER_1) using the ratio of the industrial pollution abatement and control expenditure (the sum of annual expenditures of industrial waste water treatment facilities and industrial waste gas treatment facilities for various industries) to their corresponding sales values.[3] The larger ER_1 is, the greater intensity of environmental regulation for this industry becomes. At the same time, the intensity of environmental regulation (ER_2) is denoted by the industrial pollution abatement and control expenditure (the sum of annual expenditures of industrial waste water treatment facilities and industrial waste gas treatment facilities in various industries) divided by the main industrial business costs. The empirical analysis of this paper mainly focuses on ER_1, and ER_2 will be used for subsequent robustness test. The data is collected from *China Environment Yearbooks*, *China Statistical Yearbooks on Environment,* and *China Industry Statistical Yearbooks*.

3.2.3. Control variables

In order to obtain a robust estimation, we include a vector of industry-level control variables as follows. Relative size of industry (Size): represented by the sales value of an industry divided by the total sales value of the entire industrial sector. Gross profit margin (GPM): profitability of an industry, which is the difference between its main business income and its main business cost divided by the primary business costs. Ownership structure (OS): represented by the state-owned and state-controlled paid-in capital of an industry divided by its total paid-in capital. Labor productivity (LP): the production value created by a single industrial worker, which is represented by the sales value of an industry divided by the number of its employed person. Table 2 summarizes the descriptive of key variables that are used in this study during the period 2000–2014.

[2] Since the producer price indexes for industrial products of subdivided industries in the industrial sector are missing for the years of 2000 and 2002, this paper assumes that the producer price index for the MWC is the same as that of the Coal Industry during these two years. The index for the PPCPNF is the same as that of the Petroleum Industry. The index for the MRCMCP is the same as that of the Chemical Industry. The index for the MNMP is the same as that of the Building Materials Industry. The index for the SPFM is the same as that of the Machinery Industry. The index for the SPNM is the same as that of the Forest Industry. The index for the PSEPHP is the same as that of the Electric Power Industry.

[3] Due to the lack of data, this paper assumes that the annual expenditure of industrial waste water treatment facilities and annual expenditure of industrial waste gas treatment facilities of the MWC is consistent for the years of 2000 and 2001. The unit of environmental regulation intensity is 10,000 RMB/billion RMB.

Table 2
Descriptive statistics of variables.

Variable	Description	Mean	Std.Dev.	Min	Max
TFP	Total factor productivity	0.829	0.218	0.386	1.215
TECH	Technical progress index	0.737	0 .133	0.411	0.950
EFFCH	Technical efficiency index	1.163	0.353	0.476	2.138
ER	Environmental regulation intensity	47.29	30.46	6.67	178.91
Size	Relative size of industry	0.056	0.024	0.015	0.110
GPM	Gross profit margin	0.151	0 .066	0.019	0 .328
OS	Ownership structure	0.602	0.233	0.126	0 .939
LP	Labor productivity	24.85	28.56	3.040	114.68

4. Results and discussions

4.1. Results of OLS estimation

In order to check the existence of strong PH effect for China's CIIs, the least squares estimation method is used to examine the relationships between environmental regulation intensity and industrial TFP along with the two components: technical change and technical efficiency. The regression results are shown in Table 3. Models (1) and (2) are the regression results of environmental regulation intensity for industrial TFP, Models (3) and (4) are for technical change, and Models (5) and (6) are for technical efficiency; where Models (1), (3) and (5) show the effects of the core variables on the explained variables, while Models (2), (4) and (6) indicate the impacts after adding the control variables.

It can be seen from Table 3 that there is a significant inverted U-shaped relationship between the environmental regulation intensity and industrial TFP, implying the inexistence of strong PH effect for China's CIIs in a long run. Moreover, with the enhancement of environmental regulation intensity, industrial TFP first increases and subsequently decreases with the optimal environmental regulation intensity at 115. During the whole studied period, the average environmental regulation intensity is 47 for China's CIIs, which is far from the optimal environmental regulation intensity. Except for the PSEPHP Industry, the environmental regulation intensities of the rest 6 industries are still insufficient from the turning points on the inverted U-shaped curve. There is also a quite significant inverted U-shaped relationship between environmental regulation intensity and industrial technical change. With the enhancement of environmental regulation intensity, industrial technical change increases first and then decrease, and the optimal intensity (for achieving the highest industrial technical change) is 66. At present, the PSEPHP and the SPFM have surpassed the optimal intensity. Furthermore, there is not a significant inverted U-shaped relationship between environmental regulation and industrial technical efficiency.

4.2. Endogeneity treatment and 2SLS estimation

The prerequisite for estimation consistency of the least square method is that the explanatory variables are all exogenous. However, the causal relationship between environmental regulation and TFP may be bidirectional (Rubashkina et al., 2015), which fails to satisfy the conditions of estimation consistency. Therefore, an instrumental variable is required to overcome the endogeneity issues. The instrumental variable used in this paper is a one period lag of environmental regulation intensity. Firstly, the one-period lag in environmental regulation intensity satisfies the assumption of correlation. That is, the lag period effect exists in both technical change and technical efficiency improvement, so the one-period lag in environmental regulation intensity is closely related to the environmental regulation intensity in the current period. Secondly, the one-period lag in environmental regulation intensity satisfies the exogenous principle. Since the one-period lag in environmental regulation has already occurred, the TFP in the current period cannot affect the past environmental regulation intensity, and thus it is used as an instrumental variable in this paper. In order to further test the robustness of the effect of environmental regulation on industrial TFP, some control variables including labor productivity, ownership structure, gross profit rate, and relative industry size are added one after another in Columns (1) to (5) of Table 4.

The first-stage regression results of 2SLS show that the coefficients of instrumental variable are all positive and significant at the 1% level, and the F statistic is also statistically significant. Moreover, the second-stage regression results of 2SLS show that both the Anderson canon. Corr. LM statistics and the Cragg-Donald Wald F statistics are significant at the 1% level. The above results indicate that the selected instrumental variable is identifiable and valid.

The regression results when considering the instrumental variable are reported in Table 4. First of all, there are still significant inverted U-shaped relationships between environmental regulation intensity and industrial TFP as well as industrial technical change, which further verify the inexistence of strong PH of China's CIIs in the long run. Secondly, the regression coefficients of the predominant explanatory variables in Table 4 are different from those in Table 3 with OLS estimation. The turning point of the inverted U-shape curve between environmental regulation intensity and TFP is 115 in OLS regression, while it increases to 121 in 2SLS regression in Table 4, demonstrating that the optimal environmental regulation intensity would be underestimated without considering the endogenous problem. Similarly, the turning point between environmental regulation intensity and technical change has remained the same (66) when taking the endogenous problem into account.

Table 3
Strong PH -OLS regression results.

Variable	TFP		TECH		EFFCH	
	(1)	(2)	(3)	(4)	(5)	(6)
ER_1	0.00865*** (0.0019)	0.00545*** (0.0013)	0.00589*** (0.0010)	0.00554*** (0.0011)	0.00208 (0.0025)	0.00225 (0.0195)
ER_1^2	−0.00004*** (0.00001)	−0.00002*** (0.0000)	−0.00005*** (0.0000)	−0.00004*** (0.0000)	0.00004** (0.0000)	0.00001*** (0.0000)
GPM		−1.2984*** (0.2763)		−0.2010 (0.2253)		−1.5364*** (0.3911)
Size		−0.0507 (0.7594)		0.5588 (0.6195)		−1.5062 (1.0750)
OS		−0.1589** (0.0673)		−0.1471*** (0.0548)		0.0245 (0.0952)
LP		−0.00515*** (0.0007)		0.00112*** (0.0006)		−0.0085*** (0.0010)
Threshold Point	108	115	63	66	–	–
Shape	Inverted U shape	Inverted U shape	Inverted U shape	Inverted U shape	–	–
R^2	0.20	0.70	0.36	0.46	0.47	0.78
N. Observation	105	105	105	105	105	105

Note: Significance: *P < .1, **P < .05, ***P < .01.

Table 4
Strong PH-2SLS regression results.

Variable	Second Stage Result					
	TFP					TECH
	(1)	(2)	(3)	(4)	(5)	(6)
ER_1	0.01053*** (0.0028)	0.01051*** (0.0022)	0.00933*** (0.0019)	0.00612*** (0.0020)	0.00622*** (0.0021)	0.00631*** (0.0015)
ER_1^2	−0.00005*** (0.0000)	−0.00051*** (0.0000)	−0.00004*** (0.0000)	−0.00003** (0.0000)	−0.00003** (0.0000)	−0.00005*** (0.0000)
LP		−0.0043*** (0.0005)	−0.3695*** (0.0683)	−0.0048*** (0.0006)	−0.0046*** (0.0008)	−0.0012** (0.0005)
OS			−0.00322*** (0.0005)	−0.2246** (0.0726)	−0.2246*** (0.0726)	0.2009*** (0.0514)
GPM				−1.1641*** (0.3007)	−1.1742*** (0.2989)	−0.1593 (0.2116)
SIZE					−0.3296 (0.8053)	0.2521 (0.5703)
Threshold Point	104	103	123	120	121	66
Shape	Inverted U shape	Inverted U shape	Inverted U shape	Inverted U shape	Inverted U shape	Inverted U shape
Anderson canon. corr.LM	43.705 [0.0000]	43.704 [0.0000]	41.439 [0.0000]	40.158 [0.0000]	40.279 [0.0000]	40.279 [0.0000]
Cragg-Donald Wald F	38.236 [0.0000]	37.832 [0.0000]	34.067 [0.0000]	31.937 [0.0000]	31.750 [0.0000]	31.750 [0.0000]
First Stage Result						
$LagER_1$	1.0452*** (0.1621)	1.0453*** (0.1629)	1.6054*** (0.1615)	0.8761*** (0.1763)	0.8312*** (0.1766)	0.8312*** (0.1766)
Lag ER_1^2	0.5905*** (0.1840)	0.5906*** (0.1849)	0.5298*** (0.1852)	0.6089*** (0.1911)	0.6180*** (0.1911)	0.6180*** (0.1911)
F-statistics	12.47 [0.0000]	34.25 [0.0000]	40.46 [0.0000]	45.21 [0.0000]	37.28 [0.0000]	17.46 [0.0000]
R^2	0.214	0.531	0.648	0.715	0.720	0.545
N. Observation	98	98	98	98	98	98

Note: Significance: *P < .1, **P < .05, ***P < .01.

When control variables are gradually added into the model, the estimation coefficients of the key explanatory variables gradually decrease, and eventually the coefficient of ER_1 stabilizes at about 0.006, and the coefficient of ER_1^2 stabilizes at about −0.00003. This indicates that the model specification is too simple for regression (1), i.e., other factors that affect the explained variables are not considered. With the gradual adds of the control variables, the goodness of fit increases significantly, and the coefficients of environmental regulation intensity and the square of environmental regulation intensity are all statistically significant at the 5% level, indicating that the conclusions in this paper are quite robust. In addition, ER_2 is also used for the 2SLS regression to test the robustness of the regression results. Due to the space limitation, the results are not reported in this paper.

4.3. *Further analysis*

Since the inverted U-shaped relationship between environmental regulation intensity and industrial TFP has been empirically tested, we further investigate the relative locations of current environmental regulation situations for each CII to their optimal intensity. The relational graph between environmental regulation intensity and industrial TFP is plotted based on the results of two-stage least squares regression (see Fig. 4). The relationship between ER_1 and TFP is a significant inverted U-shape with the turning point at 121. Before the threshold point is reached, industrial TFP gradually increases with the enhancement of environmental regulation intensity. At this stage, the innovation offsets effect of industrial environmental regulation dominates, which surpasses the compliance costs effect. On the contrary, industrial TFP begins to decrease when the environmental regulation intensity overreaches the threshold point; in this context, the compliance costs effect of environmental regulation dominates at the second stage.

According to the locations of each CII on the inverted U-shaped curve, the current environmental regulation intensities of all the studied CIIs (excluding PSEPHP) are within the reasonable range. According to the strong PH, appropriate design of environmental regulation policies can achieve a win-win result of reducing pollution and improving industrial TFP. As a result, the intensity of environmental regulation for these carbon-intensive industries should be further enhanced so that their TFP could get improved by different extents. On the contrary, current environmental regulation situation for PSEPHP has surpassed the optimal intensity. As is known, PSEPHP is a typical energy intensive industry with huge air pollutants and CO_2 emissions. In the face of the sharp increase of China's electricity generation as well as the coal-dominated energy mix, the central government has carried out a series of very stringent environmental regulations on this industry. For instance, the Chinese government announced to further strengthen the elimination of backward production capacity (Guo Fa [2010] No. 7), which clearly pointed out that 50 million kilowatts or more of small thermal power units of the power industry needed to be phased out by the end of 2010. Moreover, the technologies such as combined heat and power generation along with renovations on coal-fired industrial boilers have also been widely popularized. In a word, the PSEPHP has been considered one of the most significant areas to fulfill energy saving and emissions reduction policies. However, much more stringent environmental regulation standards will inevitably aggravate the cost burdens of enterprises. As a result, the compliance costs effect has finally surpassed the innovation offsets effect, resulting in TFP decline.

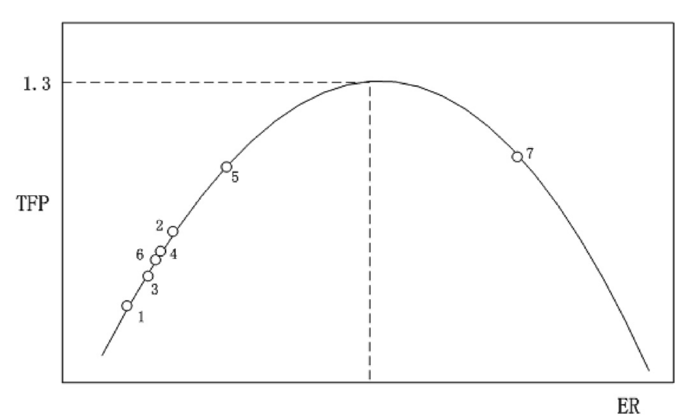

Fig. 4. Environmental Regulation and Total Factor Productivity of CIIs. Note: 1 represents Mining and Washing of Coal, 2 represents Processing of Petroleum, Coking and Processing of Nuclear Fuel, 3 represents Manufacture of Raw Chemical Materials and Chemical Products, 4 represents Manufacture of Non-metallic Mineral Products, 5 represents Smelting and Pressing of Ferrous Metals, 6 represents Smelting and Pressing of Non-ferrous Metals, 7 represents Production and Supply of Electric Power and Heat Power.

5. Conclusions and policy implications

In this paper, we try to empirically test the existence of strong Porter-hypothesis (PH) effect for China's carbon-intensive industries (CIIs). A carbon intensive index considering both the scale and intensity of CO_2 emission is first constructed to identify the CIIs, and then the non-liner relationship between environmental regulation and industrial TFP is test. In order to treat the endogenous problem of the model specification, the 2SLS model estimation method is employed. The results indicate that: (i) there is a significant inverted U-shape relationship between environmental regulation intensity and industrial TFP, which implies the inexistence of strong PH effect for China's CIIs in a long-run. With the enhancement of environmental regulation intensity, industrial TFP increases first and subsequently decreases. (ii) There is also a significant inverted U-shape relationship between environmental regulation intensity and industrial technical change, and this is quite different from the situation for technical efficiency component. (iii) Various CIIs are at dissimilar stages in terms of environmental regulation intensity: the environmental regulation for the Production and Supply of Electric Power and Heat Power Industry has exceeded the corresponding optimal intensity. On the contrary, the remaining six CIIs have not reached the optimal environmental regulation level.

Based on the conclusions drawn above, some useful policy recommendations can be put forward. First, taking the CIIs as a whole, the current environmental regulation intensity for China's CIIs is within a reasonable range, and which can even be enhanced by a certain extent. However, due to the inexistence of strong PH effect, enhancements of environmental regulation intensity by a large extent will possibly result in continuous TFP declines in a long-run. Second, since various CIIs are located in different positions on the inverted U-shaped curve, specific policy proposals should be formulated and carried out according to the different stages of environmental regulation in various industries. For example, for the 6 industries located on the left side of the inverted U-shaped curve (including MWC, PPCPNF, MRCMCP, MNMP, SPNM, and SPFM), there are moderate spaces for the enhancement of environmental regulation. On the contrary, for the PSEPHP industry which has exceeded the inflection point, the style of environmental regulation should be adjusted into a more smart way. Only by this means, a win-win result for both economic growth and environmental protection can be achieved.

Acknowledgements

The authors would like to thank the editor and anonymous referees for their very insightful and constructive comments. Financial supports from the Natural Science Foundation of China (Grants No. 71774122, 71503094, and 71303177), the Major Program of the National Social Science Foundation of China (Grants No. 16ZDA006, and 16ZDA039), and the Fundamental Research Funds for the Central Universities (2017QN035) are greatly acknowledged.

Appendix A. carbon intensive index of the 36 studied industries

Table A1
The carbon intensive index of 36 industries

Industry	Carbon emission (10^4 tons)	Ratio of carbon emission	Carbon emission intensity (tons/RMB)	Carbon intensive index
Smelting and Pressing of Ferrous Metals	148051	23.84%	22.31	0.970
Manufacture of Non-metallic Mineral Products	64481	10.38%	17.87	0.566
Manufacture of Raw Chemical Materials and Chemical Products	74853	12.05%	11.52	0.504
Mining and Washing of Coal	44275	7.13%	17.80	0.474
Smelting and Pressing of Non-ferrous Metals	39415	6.35%	12.88	0.380
Processing of Petroleum, Coking and Processing of Nuclear Fuel	60896	9.81%	7.34	0.349
Production and Supply of Electric Power and Heat Power	47536	7.66%	5.99	0.290
Manufacture of Paper and Paper Products	12492	2.01%	8.19	0.174
Manufacture of Metal Products	14308	2.30%	5.41	0.161
Manufacture of Textile	16050	2.58%	3.10	0.117
Mining and Processing of Ferrous Metal Ores	3859	0.62%	13.44	0.111
Production and Supply of Gas	3124	0.50%	10.42	0.104
Mining and Processing of Nonmetal Ores	3477	0.56%	8.48	0.093
Manufacture of General Purpose Machinery	8856	1.43%	3.04	0.084
Manufacture of Chemical Fibers	5031	0.81%	3.98	0.080
Extraction of Petroleum and Natural Gas	7980	1.29%	1.68	0.067
Production and Supply of Water	2579	0.42%	6.09	0.065
Processing of Food from Agricultural Products	8862	1.43%	1.85	0.064
Manufacture of Rubber and Plastics Products	7039	1.18%	2.59	0.062
Manufacture of Foods	4490	0.72%	2.87	0.057
Manufacture of Special Purpose Machinery	4776	0.77%	2.32	0.054
Mining and Processing of Non-Ferrous Metal Ores	2625	0.42%	3.87	0.050
Manufacture of Medicines	4070	0.66%	2.53	0.050
Processing of Timber, Manufacture of Wood, Bamboo, Rattan, Palm and Straw Products	2626	0.42%	3.89	0.046
Manufacture of Automobiles	5867	0.94%	1.61	0.044
Manufacture of Liquor, Beverages and Refined Tea	3721	0.60%	2.12	0.043
Manufacture of Electrical Machinery and Apparatus	5013	0.81%	1.06	0.028
Manufacture of Railway, Ship, Aerospace and Other Transport Equipment	2045	0.33%	1.88	0.026
Manufacture of Computers, Communication and Other Electronic Equipment	5491	0.88%	1.04	0.024
Printing and Reproduction of Recording Media	1008	0.16%	1.80	0.016
Manufacture of Textile, Wearing Apparel and Accessories	1959	0.32%	0.88	0.014
Manufacture of Leather, Fur, Feather and Related Products and Footwear	1203	0.19%	0.88	0.010
Manufacture of Measuring Instruments and Machinery	744	0.12%	1.03	0.007
Manufacture of Articles for Culture, Education, Arts and Crafts, Sport and Entertainment Activities	660	0.11%	1.05	0.006
Manufacture of Tobacco	708	0.11%	0.46	0.003
Manufacture of Furniture	520	0.08%	1.40	0.001

Appendix B. variation trend of the carbon intensive index for the 36 industries during 2000–2014

Table B1
The variation trends of carbon intensive index for 36 industries

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Smelting and Pressing of Ferrous Metals	0.82	0.86	0.94	0.93	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Manufacture of Non-metallic Mineral Products	0.50	0.55	0.48	0.49	0.69	0.62	0.55	0.57	0.61	0.59	0.60	0.63	0.56	0.53	0.53
Manufacture of Raw Chemical Materials and Chemical Products	0.45	0.47	0.58	0.54	0.64	0.56	0.55	0.56	0.56	0.45	0.43	0.44	0.45	0.44	0.44
Mining and Washing of Coal	0.60	0.59	0.59	0.58	0.48	0.43	0.41	0.37	0.36	0.33	0.40	0.45	0.54	0.49	0.49
Smelting and Pressing of Non-ferrous Metals	0.24	0.25	0.46	0.44	0.52	0.47	0.43	0.44	0.48	0.29	0.32	0.32	0.32	0.35	0.36
Processing of Petroleum, Coking and Processing of Nuclear Fuel	0.33	0.34	0.39	0.37	0.44	0.36	0.35	0.38	0.38	0.31	0.31	0.31	0.30	0.33	0.33
Production and Supply of Electric Power and Heat Power	0.27	0.27	0.36	0.33	0.38	0.32	0.31	0.30	0.32	0.25	0.25	0.27	0.25	0.25	0.22
Manufacture of Paper and Paper Products	0.16	0.16	0.20	0.17	0.23	0.21	0.20	0.19	0.20	0.16	0.16	0.16	0.14	0.14	0.13
Manufacture of Metal Products	0.06	0.06	0.23	0.23	0.26	0.24	0.25	0.29	0.31	0.07	0.08	0.08	0.08	0.08	0.08
Manufacture of Textile	0.10	0.10	0.13	0.11	0.16	0.15	0.15	0.14	0.15	0.11	0.11	0.10	0.09	0.09	0.08
Mining and Processing of Ferrous Metal Ores	0.07	0.07	0.10	0.10	0.12	0.12	0.13	0.14	0.13	0.10	0.12	0.12	0.11	0.11	0.11
Production and Supply of Gas	0.16	0.16	0.17	0.14	0.15	0.13	0.11	0.10	0.09	0.06	0.07	0.06	0.06	0.05	0.04
Mining and Processing of Nonmetal Ores	0.11	0.11	0.13	0.14	0.12	0.09	0.09	0.10	0.10	0.07	0.07	0.07	0.07	0.06	0.06
Manufacture of General Purpose Machinery	0.05	0.06	0.09	0.08	0.11	0.10	0.11	0.11	0.12	0.07	0.08	0.09	0.07	0.06	0.06
Manufacture of Chemical Fibers	0.12	0.12	0.13	0.10	0.11	0.09	0.08	0.08	0.07	0.06	0.05	0.05	0.05	0.05	0.05
Extraction of Petroleum and Natural Gas	0.14	0.14	0.17	0.13	0.09	0.06	0.04	0.04	0.04	0.04	0.03	0.02	0.02	0.02	0.02
Production and Supply of Water	0.09	0.09	0.09	0.07	0.08	0.07	0.06	0.06	0.06	0.05	0.05	0.05	0.05	0.05	0.05
Processing of Food from Agricultural Products	0.07	0.08	0.09	0.06	0.07	0.07	0.07	0.07	0.07	0.06	0.06	0.05	0.05	0.05	0.04
Manufacture of Rubber and Plastics Products	0.06	0.07	0.04	0.04	0.05	0.05	0.05	0.05	0.05	0.08	0.08	0.08	0.08	0.08	0.07
Manufacture of Foods	0.06	0.06	0.07	0.05	0.07	0.06	0.06	0.06	0.07	0.05	0.05	0.05	0.05	0.05	0.04
Manufacture of Special Purpose Machinery	0.04	0.04	0.07	0.07	0.08	0.07	0.07	0.07	0.08	0.04	0.04	0.04	0.04	0.03	0.03
Mining and Processing of Non-Ferrous Metal Ores	0.05	0.05	0.06	0.07	0.08	0.06	0.05	0.05	0.05	0.04	0.04	0.04	0.04	0.04	0.04
Manufacture of Medicines	0.05	0.05	0.05	0.05	0.06	0.06	0.05	0.05	0.06	0.04	0.04	0.04	0.04	0.04	0.04
Processing of Timber, Manufacture of Wood, Bamboo, Rattan, Palm and Straw Products	0.03	0.03	0.03	0.03	0.05	0.06	0.05	0.06	0.06	0.05	0.05	0.05	0.05	0.04	0.04
Manufacture of Automobiles	0.04	0.04	0.05	0.04	0.05	0.04	0.04	0.04	0.05	0.04	0.05	0.05	0.04	0.04	0.04
Manufacture of Liquor, Beverages and Refined Tea	0.04	0.04	0.05	0.04	0.06	0.05	0.05	0.05	0.06	0.04	0.04	0.04	0.03	0.03	0.03
Manufacture of Electrical Machinery and Apparatus	0.01	0.01	0.02	0.02	0.03	0.03	0.03	0.03	0.04	0.03	0.03	0.03	0.03	0.03	0.03
Manufacture of Railway, Ship, Aerospace and Other Transport Equipment	0.02	0.03	0.03	0.02	0.03	0.02	0.02	0.02	0.03	0.02	0.03	0.03	0.03	0.03	0.02
Manufacture of Computers, Communication and Other Electronic Equipment	0.00	0.00	0.00	0.00	0.02	0.02	0.03	0.03	0.04	0.03	0.04	0.04	0.04	0.04	0.03
Printing and Reproduction of Recording Media	0.01	0.01	0.02	0.03	0.03	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01
Manufacture of Textile, Wearing Apparel and Accessories	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01
Manufacture of Leather, Fur, Feather and Related Products and Footwear	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Manufacture of Measuring Instruments and Machinery	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00
Manufacture of Articles for Culture, Education, Arts and Crafts, Sport and Entertainment Activities	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.01
Manufacture of Tobacco	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Manufacture of Furniture	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01

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