Environmental Regulations and Competitiveness:

Popp, 2006; Lanoie et al., 2011).

This study employs a rich Chinese firm-level dataset to evaluate the effects of Chinese environmental regulations on productivity of firms. As a rapidly-growing developing country, China provides a unique context to study the effects of environmental regulations. In the last three decades, China's remarkable economic growth dwarfed many other economies, but it has also brought serious environmental degradation. In recent years, recognizing the danger of environmental degradation and the increasing popular demand for better environmental quality, the Chinese government has implemented various pollution control policies.

A few studies in the literature investigate the impacts of environmental regulations and industrial pollution controls in China. For example, Jiang et al. (2014) examine firm-level emission data and find that both foreign-owned firms and domestic publicly-listed firms show less intensive pollutant emissions compared to state-owned enterprises (SOEs). The study also finds that larger firms, firms in industries that export more, and firms with more educated employees pollute less; and that better property rights protection is negatively correlated with pollutant discharges over and beyond the national standards. Jefferson et al. (2013) exploit the plausibly exogenous variation in regulatory stringency generated by the Two Control Zone policy in China to find evidence that environmental regulations induce pollution-intensive firms to improve economic performance, whereas energy-intensive firms suffer from negative externalities of the regulations.

The current paper is one of the first studies to systematically look at the effect of different pollution control regulations on firm productivity. Environmental regulations may affect productivity at the firm-level in at least two ways. First, compliance with environmental regulations may require firms to divert inputs - capital, labor, material inputs, etc. - towards the production of environmental quality, resulting in lower productivity. Second, regulations may necessitate changes in the production process and induce firms to adopt more efficient, cleaner technologies. This study presents evidence in favour of a more recent approach which views environmental policy as a positive force leading to increased productivity and enhanced competitiveness.

The analysis builds on a theoretical model where tighter environmental regulations induce firms to upgrade production technologies, resulting in both pollution reduction and productivity increase under certain conditions. The empirical analysis examines two particular policy instruments - the pollution levy (or pollutant tax) and pollution emission standards - and their effects on the total factor productivity (TFP) of firms. It finds evidence in support of the Porter hypothesis. With regards to the pollution levy, it discovers a non-linear correlation between the effective water levy and firm productivity, suggesting that a pollution levy does not necessarily harm productivity; on the contrary, higher pollution levy could induce firms to upgrade to cleaner technologies and at the same time increase productivity. In particular, the study identifies a threshold of the pollution levy where a higher levy rate corresponds to higher productivity. The paper also investigates the effects of industry-specific pollution emission standards on productivity and finds that, although the introduction of a pollution emission standard can lead to an initial drop in productivity, the negative effect diminishes over a period of three years.

The findings in this paper are different from similar studies conducted in industrialized countries, where a negative correlation is often observed between environmental regulations and productivity. The discovery of a non-linear relationship between pollution control measures and productivity in China is of important policy relevance. Compared with industrialized countries which find themselves at the efficient production frontier, firms in a developing country like China tend to rely on low production technologies, and are therefore more likely to switch to cleaner and more efficient technologies in response to stringent environmental regulations, resulting in both productivity increases and emission reductions. The findings in the study can also be potentially relevant in other developing countries going through a rapid economic transition.

The remainder of the paper proceeds as follows. Section 2 gives a brief introduction of China's environmental regulations. Section 3 presents a simple model where environmental regulations in the form of a pollution levy and emission standards lead to higher productivity. Section 4 introduces the data. Section 5 specifies the empirical strategy and reports the results. Section 6 concludes.

2 Institutional background [1]

China's legal and institutional development of environmental protection goes back to the 1970s. The *Environmental Protection Law* (EPL), which was first enacted in 1979 on a provisional basis and which formally came into effect in 1989, is the main legal basis for environmental management in China. The EPL lays out general principles for environmental protection and describes key instruments for environmental management. It requires enterprises to assess the environmental impacts of proposed projects and comply with all relevant environmental standards. This statute also clarifies which environmental regulations should be managed and enforced at national level, and which ones at local

[1]Summary based on OECD (2006), Environmental Compliance and Enforcement in China: An Assessment of Current Practices and Ways Forward (Draft study presented at the second meeting of the Asian Environmental Compliance and Enforcement Network, 4-5 December 2006, in Hanoi, Vietnam). http://www.oecd.org/environment/outreach/37867511.pdf

level. In addition, the EPL recognizes the rights of organizations and individuals to report cases of pollution and le charges against polluters.

In 1988, the State Environmental Protection Agency (SEPA) was formed alongside numerous local Environmental Protection Bureaus (EPBs) throughout the nation. In 2008, SEPA was replaced by the Ministry of Environmental Protection (MEP). Over the past 30 years, many environmental protection organizations other than the EPBs have also been formed at both the national and local (provincial, city, or county) levels. According to the data released by MEP, China had established 12,215 environmental protection

a basis for the EPB inspection activities.

China issued the rst ambient environmental quality standard for surface water in 1983. The standard was subsequently updated in 1988, 1999 and 2002. In addition, the rst *Integrated Wastewater Discharge Standard* was issued in 1988 and updated in 1998. The wastewater discharge standard establishes the upper limits for 69 pollutant concentrations and the allowable water discharges for some industries. In addition, a range of water discharge and emission standards target speci c industries including chemicals, coal mining and processing, electroplating, iron and steel, municipal wastewater treatment, pharmato the technology. I de ne k_i by integrating the amount of labor l_i over time , from 0 to t

$$\frac{df}{dw} = N \tag{4}$$

However, the individual agent does not take into account the degree to which its output reduces environmental quality. Therefore, without any government intervention, the agent produces until the marginal product of waste reaches zero. The market equilibrium results in $df/dw = 0$ and $w = w$ in every period.

3.1 New technology

Now I assume that there is a new technology g, which can also be used to produce c. For any given level of inputs, the new technology is more efficient than the old technology. With the same amount of inputs, production using the new technology yields more output:

$$f(l; w; k) < g(l; w; k) \quad \text{for any given } l; w; k \tag{5}$$

Equation (5) implies that technology g is also "cleaner" than technology f in the sense that, for a given level of labor and capital, it can produce the same amount of output with less waste. To clarify this point, suppose that all agents initially use technology f. I now define a function $b(l; w; k)$ that equals the unit waste the producer could abate without sacrificing output. In other words, the waste abatement b satisfies

$$f(l; w_f; k) = g(l; w_f - b; k) \quad \text{for any given } l; w; k \tag{6}$$

The subscripts f and g designate the two technologies: the new and the old. From any starting value of w_f, the function b identifies the maximum environmental benefits that can be achieved without imposing any long-term production costs. Alternatively, the new technology g can produce more output with the same amount of l, w and k.

In every period, the agent chooses a technology of production. The total supply of labor L can be divided into the amount of labor for each of the two technologies: $L = \sum l_f + \sum l_g$. Likewise, total waste is the sum of the waste produced by the two technologies at time t. Therefore, $W = \sum w_f + \sum w_g$. For the whole economy, $N = N_f + N_g$.

Capital is divided between the two technologies. Assuming that at time t_s the agent switches from technology f to technology g, the capital used in technology f at time t is $k_{ft} = \int_0^{t_s} l_f \, d\tau$, and the capital dedicated to technology g is $k_{gt} = \int_{t_s}^{t} l_g \, d\tau$.

Technology switching has short-term costs. In the initial period after g is introduced, the agent has larger cumulated investment in f than in g. There exists some period of time , such that

$$\text{if} \quad t \quad t_s \quad < \quad , \text{ then } f \quad l; w; k \quad > g \quad l; w; k \quad \text{for any given } l; w \tag{7}$$

In the long-run, the agent accumulates capital in the new technology g, and productivity

3.2 Environmental regulations

Consider a scenario in which the government introduces a regulation that favors or requires the use of a new, clean technology. As a result, agents switch to the new technology, and rms can all increase long-term productivity.

For the society, the optimal level of pollution is decided by equating the marginal social cost of pollution with the marginal bene t of production in every period. Therefore, the government, recognizing that society has t years of experience with technology f, will choose to switch to technology g if:

$$\int_{t}^{1} (\quad t)\; g \;\; l_g; w_g; k_g \qquad W_g \;\; d \;\; > \int_{t}^{1} (\quad t)\; f \;\; l_f; w_f; k_f \qquad W_f \;\; d \tag{8}$$

Suppose now that the government charges a pollution levy r on waste w. The agent produces until the marginal product of waste equals the levy rate. The agent switches to technology g if the profit (i.e. total output minus the levy payment) using technology g is bigger than the profit using technology f.

$$g(l_g; w_g; k_g) - rw_g > f(l_f; w_f; k_f) - rw_f \tag{10}$$

In the ideal situation where the levy rate equals the social cost of pollution, each agent's decision would equal the socially optimal.

To sum up, the model allows conditions under which a government intervention induces firms to switch to a more efficient technology and thus raises the productivity in the long-run, even though output in the short-run might be compromised. To do so, however, two strong assumptions must hold. First, a more productive but unused technology must be available. Second, environmental policy can only improve productivity if it favors a

4 Data

The data in the empirical analysis are gathered from two main sources. The rm-level

Table 1: Types of Chinese industrial enterprises by ownership

Year	Total number of Firms	State -owned	Collectively -owned	Private	Foreign -invested	HK, Macao, TW-invested
1998	165,118	60,719	50,934	26,621	17,637	12,400
1999	162,033	54,900	46,479	29,466	17,086	13,151
2000	162,883	46,652	40,376	37,212	16,588	14,132
2001	171,240	40,023	34,823	50,391	17,295	15,443
2002	181,557	34,758	30,769	63,439	19,058	15,930
2003	196,222	28,628	24,637	78,448	20,181	17,913
2004	274,763	27,002	23,822	123,310	28,427	25,400
2005	271,835	21,724	20,476	126,928	29,480	24,604
2006	301,961	19,847	20,061	148,004	32,147	26,136
2007	336,768	13,305	16,431	166,824	32,543	28,357

to estimate firm TFP. For example, Levinsohn and Petrin (2003)(LP) use an intermediate input demand function to reveal productivity. LP consider intermediate inputs such as electricity, fuel, or materials as a "proxy" for unobserved productivity. However, Ackerberg et al. (2006) point out that the LP estimation suffers from a collinearity problem in the first stage estimation.

Below I briefly describe the OP method. Olley and Pakes (1996) assume that productivity ω_{it} evolves exogenously following a first-order Markov process. Capital is assumed to be a dynamic input subject to an investment process. In every period, the firm decides on an investment level i_{it}, which adds to future capital stock deterministically. In contrast, labor is a non-dynamic input. A firm's choice of labor for a period t has no impact on the future profits of the firm.

OP address the simultaneity problem by assuming that a firm's optimal investment level i_{it} is a strictly increasing function of their current productivity ω_{it}. The investment function can then be inverted to obtain a function of productivity ω_{it} with regards to investment i_{it} and capital k_{it}. OP use this inverse function to control for ω_{it} in the production function. The first stage of OP involves estimating the equation:

$$\begin{aligned} y_{it} &= \beta_k k_{it} + \beta_l l_{it} + \beta_m m_{it} + f^{-1}(i_{it}; k_{it}) + \epsilon_{it} \\ &= \beta_k k_{it} + \beta_l l_{it} + \beta_m m_{it} + \phi(i_{it}; k_{it}) + \epsilon_{it} \end{aligned}$$

where y_{it} is the output or value-added of firm i in year t, k_{it} indicates the capital stock, l_{it} is the labor input in production, and m_{it} is the intermediate input also assumed to be non-dynamic. The second stage of OP proceeds given the estimations of $\hat{\beta}_l$ and $\hat{\phi}_{it}$.

To address the sample selection bias, Olley and Pakes model a firm's survival probability by assuming that, at each period, a firm compares the sell-off value of its plant to the expected discounted returns of staying in business. If the current state variable indicating continuing operations is not worthwhile, the firm closes down the plant. If not, the firm chooses an optimal investment level (constrained to be non-negative). To identify β_k, OP use estimates of survival probabilities:

$$\begin{aligned} & Pr\left[\chi_{t+1} = 1 \mid \underline{\omega}_{t+1}(k_{t+1}); I_t\right] \\ = & Pr\left[\omega_{t+1} \geq \underline{\omega}_{t+1}(k_{t+1}) \mid \underline{\omega}_{t+1}(k_{t+1}); \omega_t\right] \end{aligned}$$

χ_t equal to 1 indicates the firm survives. From the assumption that k_{it} is decided before the full realization of ω_{it}, one can estimate β_k by minimizing the sample analogue of the deviation of ω_{it} from the expectations in the previous period.

Table 2 reports the estimated share of the production inputs - capital stock, labor and intermediate input - in the OP estimation. The dependent variable is the log of firms' real value-added, defined as the price-deflated RMB value of output minus raw material input. It therefore captures the value that a firm creates in the economy.

The log of capital stock k_{it} is used as a state variable, and investment i_{it} is used as a proxy for productivity. Both log labor l_{it} and intermediate input m_{it} are used as free variables in the sense that a firm's choice of l_{it} and m_{it} has no impact on the future profits of the firm.

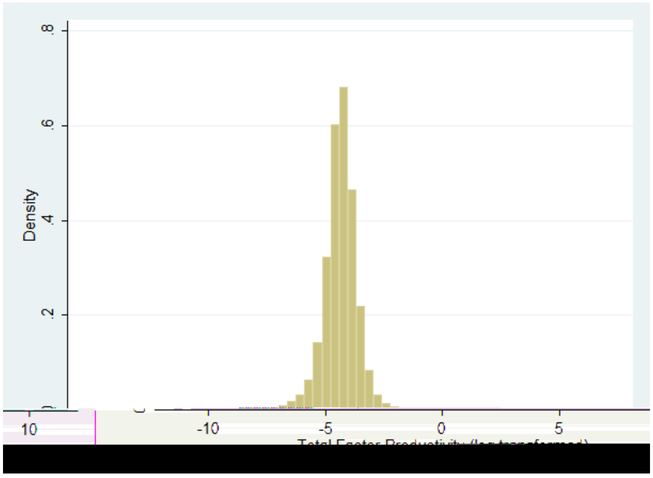
Table 2: Olley-Pakes productivity estimator

	Coefficient	Standard error
lnCapital	0.152248	0.0023732
lnLabor	0.2251768	0.0012411
lnInput	0.6280465	0.0015613
Number of firm-year observations	1314897	
Number of firms	550830	

Productivity estimation using the Olley and Pakes method
Dependent variable: log real value-added
State variable: log capital stock k_{it}
Proxy: log investment i_{it}
Free variables: log labor l_{it} and log intermediate input m_{it}

Capital stock k_{it} is calculated as the original purchasing value of the fixed capital minus the

Figure 2: Log of TFP calculated using Olley and Pakes



4.3 E ective pollution levy

The *China Environment Yearbooks* report the annual total pollution levy by province, and breaks the total pollution levy down by water pollution, air pollution and solid waste the SO_2 emission fee reported in the *China Environment Yearbook*.

To remove the e ect of in ation over the years studied, I adjust the e ective pollution

Figure 3: Average e ective pollution levy rate by province

in order to capture the degrees to which industries are affected by the environmental regulations.

The *China Environment Yearbooks* report the pollution emissions by industry according to the 2-digit divisions of Chinese industrial classification, which include 39 sectors covering mining, manufacturing, and energy supply. For each industry, the official statistics report the amount of emissions of major pollutants, such as chemical oxygen demand (COD), total suspended solids (TSS), ammonia nitrogen for wastewater, and sulfur dioxide (SO_2), nitrogen oxides (NO_x), industrial soot and dust for air pollutants. To make meaningful comparisons across pollutants, I convert all water pollutants into COD equivalents and all air pollutants into SO_2 equivalents using the conversion parameters published in official Chinese regulations. The industry-level pollution emissions are then normalized by the output per industry. I deflate the industry output by the industry-specific producer price index (PPI) in order to remove the inflation effects.[6]

Prior to 2002, Chinese industrial data were classified using GB/T 4754-1994 standard. From 2002 onward, industrial data have been classified using a new GB/T 4754-2002 standard. The new industrial classification standard has more divisions compared with the one used before 2001. The emissions and output data published from 1998 to 2000 has several industrial divisions grouped together.[7] To make meaningful comparisons of industrial pollution across years, I disaggregate these grouped data from 1998 to 2000 to match with the industrial classification used in 2001 onwards.[8]

Appendix D lists the industrial pollution intensity by measure of COD and SO_2 equivalent pollution emissions. Overall, China's industrial pollution intensity has decreased over the years studied.

[6] The data of producer price index come from two main sources: for all manufacturing sectors, I use the Chinese industry output deflator developed and described in Brandt et al. (2014); for all other sectors, including mining and energy, I use the official industry PPI released by the National Bureau of Statistics.

[7] For example, divisions 13 to 16 were grouped as "Food, Beverages and Tobacco", divisions 35 to 41 were grouped as "Machine, Electric Machinery & Electronic Equipment Mfg.", and divisions 44 to 46 were grouped as "Production and Supply of Electric Power, Gas, and Water".

[8] I first create corresponding groups for the years 2001 to 2003 by summing the appropriate division data for each group, and calculate the average share of emissions of each pollutant attributable to a division within the group. I then apply these shares to the grouped data in the early period. Each group's annual emission data from 1998 to 2000 for each pollutant was multiplied by the corresponding average share to derive the missing annual emissions data for each division within that group. I follow a similar procedure to derive the missing output data for each division within each group.

5 Empirical speci cations and results

This section explains the empirical models to estimate the e ects of pollution levy and emission standards on the productivity of rms. It also reports the estimation results for the two policy measures - the pollution levy and emission standards - respectively.

5.1 Pollution levy

I employ the following estimation model to analyze the e ect of pollution levy on productivity.

$$TFP_{ijpt} = {}_0 + {}_1 PI_{jt} \quad L_{pt} + {}_2 PI_{jt} \quad L_{pt}{}^{2} + {}_3 PI_{jt} \quad L_{pt}{}^{3} \\ + \quad X_{it} + v_{pt} + v_{jt} + v_{jp} + "_{ijpt} \quad (11)$$

the subscripts $i; j; p; t$ represent the rm, industry, province and time. TFP_{ijpt} is the natural logarithm of a rm's total factor productivity, PI_{jt} stands for the pollution intensity of the industry j in year t, L_{pt} is the e ective (water and air) pollution levy in province p and in year t. X_{it} is a set of rm-speci c control variables. In addition, I include v_{pt}, v_{jt} and v_{jp} to account for the province-by-year, industry-by-year and province-by-industry xed e ects. $"_{ijpt}$ is the idiosyncratic error term.

The interaction term $PI_{jt} \quad L_{pt}$ represents the pollution levy intensity. Essentially, a higher pollution levy intensity means that industry j in province p is subject to a higher pollution levy. To test whether rm productivity has a non-linear relationship with regards to environmental regulations as predicted in d [srovince

Song et al., 2011). Moreover, the size of a rm, the number of years since its establishment, whether the rm exports to foreign markets and the capital-labor ratio could also a ect productivity (Syverson, 2011). I include the ownership type, rm size, age, export status and capital-labor ratio to control for the factors likely to a ect the productivity of a rm.

The size of a rm is de ned by the number of employees. The capital labor ratio is de ned as the capital stock divided by the number of employees. The age is the number of years since the rm was established. A binary indicator variable *Foreign* equals 1 if more than 25% of the rm's registered capital is from investors outside of China; *hkmctw* indicates if an enterprise has over 25% of its capital from investors based in Hong Kong, Macao or Taiwan; *S.O.E.* indicates a state-owned enterprise if over 51% of the registered capital is state-owned; variable *Private* equals 1 if over 50ETJ/F17 11.8(on7 11-344(r)-2o)27(wn44(f)1(%if)

Table 4: Water and Air Levy Rate on TFP

	(1)	(2)	(3)	(4)	(5)	(6)
	TFP	TFP	TFP	TFP	TFP	TFP
COD Equivalent Pollution Intensity						
Water Levy	0.0013	-0.0014	-0.0064	0.0018	-0.0002	-0.0045
	(0.0012)	(0.0017)	(0.0027)	(0.0012)	(0.0017)	(0.0026)
Water Levy^2		0.0020	0.0085		0.0015	0.0070
		(0.0009)	(0.0029)		(0.0009)	(0.0029)
Water Levy^3			-0.0014			-0.0012
			(0.0006)			(0.0006)
SO^2 Equivalent Pollution Intensity						
Air Levy	-0.0062	-0.0141	-0.0208	-0.0069	-0.0135	-0.0181

RMB output).

The effect of the air pollution levy on total factor productivity suggest a more clear negative correlation. The linear term of the levy interacting with air pollution intensity is negatively correlated with productivity, suggesting that a negative relationship exists between the air pollution levy and firm productivity. On average, a one-unit increase in the effective pollution levy is associated with a drop of 0.6% in total factor productivity. The interaction of industry pollution intensity with the quadratic and cubic terms of the air pollution levy is also significantly correlated with firm productivity. I plot the cubic and quadratic relationship of the air pollution levy and productivity in Appendix A.

In general, I find a bell-shaped relationship between water pollution levy and productivity, while air pollution levy displays a more clear negative correlation with productivity. At first glance, it may seem paradoxical that higher productivity can be associated with a higher pollution levy. However, the theoretical model discussed in Section 3 presents such a possibility: when the pollution levy is low, firms may opt for paying the pollution levy or for diverting some of their resources towards pollution abatement, resulting in lower productivity. However, when the pollution levy rate is above a certain level, firms may find it more profitable to switch to new, cleaner technologies, resulting in both reductions in pollution and increases in productivity.

order to control for time-varying industry trends that might affect productivity and pollution emission standards, I include in the differenced question two-digit industry dummies that account for unobserved trends at broad sector levels.

$$TFP_{ijp} = {}_j + \sum_{t=1}^{T} {}_t \; S_{jp} + \varepsilon_{ijp} \tag{13}$$

Still, there can still be important differences between provinces that are likely to affect environmental standards. In order to control for these factors, I include in some specifications the following control variables: per capita GDP of the province, the effective water and air pollution levies as indicators of environmental stringencies in the province.

$$TFP_{ijp} = {}_j + \sum_{t=1}^{T} {}_t \; S_{jp} + {}_1 GDP \; + GDP$$

v9552 Tf9.7 0.9701 ia Tf61.301 1.793 Td [(+)]TJ/F20 1

Table 5: Water and Air Pollution Standards on TFP

	(1)	(2)	(3)	(4)	(5)	(6)
	TFP	*TFP*	*TFP*	*TFP*	*TFP*	*TFP*
Standard $_{year1}$	-0.0248	-0.0418	-0.0269	-0.0443	-0.0277	-0.0449
	(0.0142)	(0.0181)	(0.0139)	(0.0178)	(0.0134)	(0.0176)
Standard $_{year2}$	-0.0238	-0.0379	-0.0267	-0.0411	-0.0274	-0.0413
	(0.0111)	(0.0269)	(0.0104)	(0.0261)	(0.0092)	(0.0250)
Standard $_{year3}$	-0.0070	-0.0105	-0.0097	-0.0145	-0.0100	-0.0153
	(0.0144)	(0.0336)	(0.0146)	(0.0334)	(0.0150)	(0.0327)
Standard $_{year4}$	0.0093	0.0109	0.0075	0.0073	0.0074	0.0062
	(0.0110)	(0.0316)	(0.0111)	(0.0317)	(0.0115)	(0.0312)
Standard $_{year5}$		0.0103		0.0080		0.0063
		(0.0303)		(0.0302)		(0.0297)
Standard $_{year6}$		0.0318		0.0330		0.0307
		(0.0319)		(0.0319)		(0.0314)
GDP per capita			-0.0006	-0.0006	-0.0002	-0.0001
			(0.0001)	(0.0001)	(0.0001)	(0.0002)
Water Levy					0.0010	0.0064
					(0.0022)	(0.0031)
Air Levy					-0.0256	-0.0480
					(0.0047)	(0.0064)
constant		0.0099	0.0250	0.0248	0.0274	0.0328
		(0.0013)	(0.0020)	(0.0031)	(0.0023)	(0.0037)
Observations	543746	165036	543746	165036	543602	165036
R^2	0.0004	0.0005	0.0005	0.0008	0.0006	0.0012
F	4.6561	13.2892	11.6281	22.3138	12.0312	43.9312

Dependent variable to rst di erence of total factor productivity of a rm. Standard errors are reported in parentheses. < 0:10, < 0:05, < 0:01

5.3 Endogeneity

The analysis assumes that environmental policies are *exogenously* imposed. A potential issue in the analysis can be associated with the possibility that the environmental regulation measures are *endogenously* determined by the productivity of rms. One source of endogeneity can be related to the fact that local authorities can exercise considerable discretion on rm pollution levies. For example, Wang et al. (2003) nd evidence that state-owned enterprises have greater bargaining power with local environmental authorities and can thus successfully negotiate lower e ective levy rates. Firm productivity might therefore be a reason, rather than a result, of the pollution levy it is subject to. However, the reverse causality is less of a concernscan exercise considerable

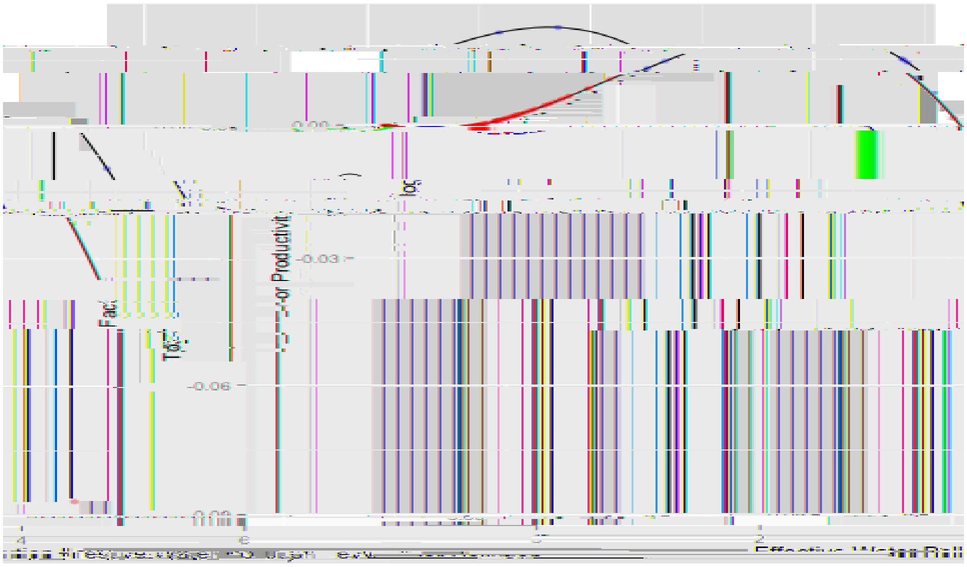
3.5 RMB for roughly per thousand RMB output, and decreases when the pollution levy rate exceeds 3.5 RMB. For the air pollution levy, one can observe a negative correlation between the levy rate and productivity. On average, a one-unit increase in the pollution levy is associated with a drop of 0.6% in total factor productivity.

An analysis of China's regulatory standards finds that emission standards have a negative initial effect on firm productivity but a positive effect in the long-run. An industry-specific pollution standard can be associated with a 2-4% reduction in productivity in the same year that the standard is adopted. The negative effects can last up to three years, but higher environmental standards eventually diminishes and are sometimes correlated with higher productivity. The finding is consistent with the Porter hypothesis whereby environmental standards can induce firms to upgrade technology and increase productivity.

The empirical study in this paper focuses on the correlation, not causality, between pollution control policies and productivity. However, as provincial-level pollution levies and industry-specific pollution emission standards are not likely to be affected by the productivity of individual firms, the policy measures discussed in the study can be thought of as largely exogenous.

The empirical analysis in this paper finds evidence in support of the Porter hypothesis. While similar studies conducted in industrialized countries often find negative correlation between environmental regulations and productivity, the discovery of a positive or sometimes non-linear relationship between pollution control measures and productivity in China suggests that environmental regulations can be associated with productivity increases. As firms in a developing country like China tend to rely on low production technologies, they are more likely to switch to cleaner and more efficient technologies in response to stringent environmental regulations.

Appendix A - Correlation of pollution levy and TFP



Estimated relationship of water levy and productivity excluding control variables. The blue dots are the actual e ective pollution levy rates.

Estimated relationship of water levy and productivity including control variables. The blue dots are the actual e ective pollution levy rates.

chemicals and the volume of wastewater.

Table 6: Pollution levy collection in China, 1992-2002
(10 000 RMB)

Year	Total	From Emissions above standards					From wastewater discharge fee	From penalties	From SO2 fee
		Water	Air	Solid waste	Noise	Radioactive wastes			
1992	239,452	118,673	50,859	3,079	8,930	1,037	8,485	48,389	
1993	268,013	122,838	56,021	3,747	11,930	20	12,637	60,821	
1994	309,757	132,197	64,498	3,199	15,551	89	20,046	74,177	
1995	371,281	150,365	74,297	4,846	19,019	166	25,384	97,204	
1996	409,594	155,135	67,212	3,743	21,413	183	28,791	118,542	14,575
1997	454,332	164,194	67,682	5,015	24,417	151	30,521	139,799	22,553
1998	490,194	163,746	65,491	4,394	26,410	77	28,281	150,285	51,510
1999	554,512	166,521	69,757	5,956	30,549	383	29,089	166,124	86,133
2000	579,607	172,217	76,104	6,998	34,234	472	27,320	184,658	77,603
2001	621,802	175,803	72,052	8,592	34,864	139	23,521	196,475	110,358
2002	674,376	179,524	79,063	8,983	37,539	252	27,920	218,673	122,424

For a plant i that discharges within the pre-speci ed concentration standards, the levy for wastewater discharge is based on the total volume of wastewater discharge W and the central and local governments. The charge rate R is determined relative to a critical factor T; both R and T are set by the central government and vary by pollutant, but not by industry. The potential levy L_j is calculated for each pollutant; the actual levy is the greatest of the potential levies.

Table 7 lists the national standards on the pollution levy rates R, threshold parameters T and xed payment L_{0j} for the most common water pollutants[9].

Table 7: Pollution charge standards for common water pollutants

Pollutant	Regulatory Threshold T_j	Levy Charge Standard R_2 (RMB/tons)	Levy Charge Standard R_1 (RMB/tons)	Fixed Payment Factor L_{0j} (RMB)
COD	20000	0.18	0.05	2600
TSS	800000	0.03	0.01	16000
Mercury	2000	2.00	1.00	2000
Cadmium	3000	1.00	0.15	2550
Petroleum	25000	0.20	0.06	3500
Ammonia Nitrogen	25000	0.10	0.03	1750
Hexavalent Chrome	150000	0.09	0.02	10500
Arsenic	150000	0.09	0.02	10500
Lead	150000	0.08	0.03	7500
Volatile Hydroxybenzene	250000	0.06	0.03	7500
Cyanide	250000	0.07	0.04	7500
Sul de	250000	0.05	0.02	7500

The levy formula for air pollution is

$$L_{ij} = Max\left[0; R_j V_i (C_{ij} \quad C_{sj})\right] \tag{17}$$

where, for plant i and pollutant j, R_j is the charge rate for pollutant j, V_i the total volume of air emissions, C_{ij} the pollution concentration, C_{sj} the concentration standard, L_{ij} the total levy. The charge is zero when the pollutant concentration C is less than or equal to the standard C_s. Unlike the water levy, the air levy is assessed on the absolute, rather than percentage, deviation from the concentration standard. Again, a rm is assessed only by the highest of its potential levies.

There are four major sources of provincial variation in pollution tax rates. First, as noted above, concentration standards C_{sj} are set jointly by the national and local governments

where E_{ij} is the equivalent discharge for pollutant j; P_{ij} is the emission/discharge of pollutant j in plant i, and F_j is a conversion parameter for pollutant j. The equivalent discharge for each pollutant j is calculated as the plant i's total emission of pollutant j (in kg) divided by the conversion parameter F_j. The pollutants that are more likely to cause environmental damage are assigned a smaller conversion parameter and have greater amount of the equivalents.

lent, and for air pollutants, the marginal levy rate is 0.6 RMB per unit of SO_2 equivalent for the within-standard discharge. The rates are doubled for discharges that are higher than the standards, i.e. 1.4 RMB and 1.2 RMB for COD and SO_2 equivalent, respectively.

To illustrate the difference between the pre- and post-2003 levy systems, I assume there are two plants, each emitting a total of 500,000 tons of wastewater with three particular pollutants: COD, TSS and Ammonia Nitrogen. One plant emits within the standards and the other exceeds the standards. Table 10 shows the potential levy charge under the pre- and post-2003 regulations. For the within-standard polluter, the levy under the new pollution regulation increased slightly. For the above-standard polluter, the levy under the new regulation is almost five times the levy under the pre-2003 regulations. The comparisons show that the post-2003 system penalizes heavy polluters substantially more.

Table 10: Comparison of potential levy under different pollution levy regulations

	Actual Concentration (mg/L)	Concentration Standard (mg/L)	Pollutant Discharge (kg)	Levy Amount	
				Pre-2003 (RMB)	Post-2003 (RMB)
Within-standard polluter:					
COD	50	100	25,000		17,500
TSS	50	70	25,000		4,375
Ammonia Nitrogen	10	30	5,000		4,375
Total actual levy (RMB)				25,000	26,250
Above-standard polluter:					
COD	200	100	100,000	27,600	103,500
TSS	350	70	175,000	36,000	55,125
Ammonia Nitrogen	50	30	25,000	2,500	21,875
Total actual levy (RMB)				36,000	180,600

Appendix C.2 - National pollution emission standards

Doc No.	Document Title	Pollutant	Publication Date	E ective Date
GB 3095-1996	Ambient air quality standards	air	8-Jan-1996	1-Oct-1996
GB 16171-1996	Emission standard of air pollutants for coke oven	air	7-Mar-1996	1-Jan-1997
GB 16297-1996	Integrated emission standard of air pollutants	air	12-Apr-1996	1-Jan-1997
GB 9078-1996	Emission standard of air pollutants for industrial kiln and furnace	air	7-Mar-1996	1-Jan-1997
GB 8978-1996	Integrated wastewater discharge standard	water	4-Oct-1996	1-Jan-1998
GB 3097-1997	Sea water quality standard	water	3-Dec-1997	1-Jul-1998
GB 13271-2001	Emission standard of air pollutants for coal-burning oil-burning gas- red boilers	air	12-Nov-2001	1-Jan-2002
GB 13458-2001	Discharge standard of water pollutants for ammonia industry	water	12-Nov-2001	1-Jan-2002
GB 18483-2001	Emission standard of cooking fume (on trial)	air	12-Nov-2001	1-Jan-2002
GB 18486-2001	Standard for pollution control of sewage marine disposal engineering	water	12-Nov-2001	1-Jan-2002
GB 3544-2001	Discharge standard of water pollutants for paper industry	water	12-Nov-2001	1-Jan-2002
GB 3838-2002	Environmental quality standards for surface water	water	28-Apr-2002	1-Jun-2002
GB 18596-2001	Discharge standard of pollutants for livestock and poultry breeding	water	28-Dec-2001	1-Jan-2003
GB 14470.1-2002	Discharge standard for water pollutants from ordnance industry - Powder and explosive	water	8-Nov-2002	1-Jul-2003
GB 14470.2-2002	Discharge standard for water pollutants from ordnance industry - Initiating explosive material and relative composition	water	8-Nov-2002	1-Jul-2003
GB 14470.3-2002	Discharge standard for water pollutants from ordnance industry - Ammunition loading	water	8-Nov-2002	1-Jul-2003
GB 18918-2002	Discharge standard of pollutants for municipal wastewater treatment plant	water	24-Dec-2002	1-Jul-2003
GB 13223-2003	Emission standard of air pollutants for thermal power plants	air	30-Dec-2003	1-Jan-2004
GB 19430-2004	Discharge standard of pollutants for citric acid industry	water	18-Jan-2004	1-Apr-2004
GB 19431-2004	Discharge standard of pollutants for monosodium glutamate industry	water	18-Jan-2004	1-Apr-2004
GB 4915-2004	Emission standard of air pollutants for cement industry	air	15-Dec-2004	1-Jan-2005
GB 18466-2005	Discharge standard of water pollutants for medical organization	water	27-Jul-2005	1-Jan-2006
GB 19821-2005	Discharge standard of pollutants for beer industry	water	18-Jul-2005	1-Jan-2006
GB 20426-2006	Emission standard for pollutants from coal industry	water, air	1-Sep-2006	1-Oct-2006
GB 20425-2006	Discharge standard of water pollutants for sapogenin industry	water	1-Sep-2006	1-Jan-2007

Doc No.	Doc Title	Pollutant	Publication Date	E ective Date
GB 20950-2007	Emission standard of air pollutant for bulk gasoline terminals	air	22-Jun-2007	1-Aug-2007
GB 20951-2007	Emission standard of air pollutant for gasoline transport	air	22-Jun-2007	1-Aug-2007
GB 20952-2007	Emission standard of air pollutant for gasoline lling stations	air	22-Jun-2007	1-Aug-2007
GB 21522-2008	Emission Standard of Coalbed Methane/Coal Mine Gas (on trial)	air	2-Apr-2008	1-Jul-2008
GB 21523-2008	E uent Standards of Pollutants for Heterocyclic Pesticides Industry	water	2-Apr-2008	1-Jul-2008
GB 21900-2008	Emission standard of pollutants for electroplating	water, air	25-Jun-2008	1-Aug-2008
GB 21901-2008	Discharge standard of water pollutants for down industry	water	25-Jun-2008	1-Aug-2008
GB 21902-2008	Emission standard of pollutants for synthetic leather and arti cial leather industry	water, air	25-Jun-2008	1-Aug-2008
GB 21903-2008	Discharge standards of water pollutants for pharmaceutical industry- Fermenta-			

Doc No.	Doc Title	Pollutant	Publication Date	E ective Date
GB 25468-2010	Emission standard of pollutants for magnesium and titanium industry	water, air	27-Sep-2010	1-Oct-2010
GB 26131-2010	Emission standard of pollutants for nitric acid industry	water, air	30-Dec-2010	1-Mar-2011
GB 26132-2010	Emission standard of pollutants for sulphuric acid industry	water, air	30-Dec-2010	1-Mar-2011
GB 15580-2011	Discharge standard of water pollutants for phosphate fertilizer industry	water	2-Apr-2011	1-Oct-2011
GB 26451-2011	Emission Standards of pollutants from rare earths industry	water, air	24-Jan-2011	1-Oct-2011
GB 26452-2011	Discharge standard of pollutants for vanadium Industry	water, air	2-Apr-2011	1-Oct-2011
GB 26453-2011	Emission standard of air pollutants for at glass industry	air	11-Apr-2011	1-Oct-2011
GB 13223-2011	Emission standard of air pollutants for thermal power plants	air	29-Jul-2011	1-Jan-2012
GB 14470.3-2011	E uent standards sg4f air pollutants for	water	2-Apr-20911	1-Oct62012

Appendix C.2 - Provincial emission standards

Doc No.	Province	Document Title	Pollutant	E ective Date
DB11/206-2003	Beijing	Emission Controls and Limits for Gasoline Vapor on Bulk Gasoline Terminals	air	2003.10.01
DB11/207-2003	Beijing	Emission Controls and Limits for Gasoline Vapor on Tank Truck	air	2003.10.01
DB11/208-2003	Beijing	Emission Controls and Limits for Gasoline Vapor on Gasoline Filling Station	air	2003.10.01
DB11/307-2005	Beijing	Discharge Standard of Water Pollutants	water	2005.09.01
DB11/447-2007	Beijing	Emission Standards of Air Pollutants for Petroleum Re ning and Petrochemicals Manufacturing Industry	air	2007.07.01
DB11/139-2007	Beijing	Emission Standard of Air Pollutants for Boilers	air	2007.09.01
DB11/501-2007	Beijing	Integrated Emission Standards of Air Pollutants	air	2008.01.01
DB11/502-2007	Beijing	Emission Standard of Air Pollutants for Municipal Solid Wastes Incineration	air	2008.01.01
DB11/503-2007	Beijing	Emission Standard of Air Pollutants for Hazardous Wastes Incineration	air	2008.01.01
DB11/206-2010	Beijing	Emission Controls and Limits for Gasoline Vapor on Bulk Gasoline Terminals	air	2010.07.01
DB11/207-2010	Beijing	Emission Controls and Limits for Gasoline Vapor on Tank Truck	air	2010.07.01
DB11/208-2010	Beijing	Emission Controls and Limits for Gasoline Vapor on Gasoline Filling Station	air	2010.07.01
DB11/847-2011	Beijing	Emission standard of air pollutants for stationary gas turbine	air	2012.01.01
DB62/1922-2010	Gansu	Emission standard for air pollutants from boilers for Lanzhou City	air	2010.06.10
DB44/26-2001	Guangdong	Discharge Limits of Water Pollutants	water	2002.02.01
DB44/27-2001	Guangdong	Emission Limits of Air Pollutants	air	2002.02.01
DB44/612-2009	Guangdong	Emission standard of air pollutants for thermal power plants	air	2009.08.01
DB44/613-2009	Guangdong	Discharge standard of pollutants for livestock and poultry breeding	water, air	2009.08.02
DB44/765-2010	Guangdong	Emission Standard of Air Pollutants for Boilers	air	2010.11.01
DB44/814-2010	Guangdong	Emission standard of volatile organic compounds for furniture manufacturing operations	air	2010.11.02
DB44/815-2010	Guangdong	Emission standard of volatile organic compounds for printing industry	air	2010.11.03
DB44/816- 2010	Guangdong	Emission standard of volatile organic compounds for surface coating of automobiles	air	2010.11.04
DB44/817-2010	Guangdong	Emission standard of volatile organic compounds for shoe-making industry	air	2010.11.05
DB44/818-2010	Guangdong	Emission standard of air pollutants for cement industry	air	2010.11.06
DB13/339-1997	Hebei	Dust Environmental Quality Standards (Trial)	air	1998.05.01
DB13/831-2006	Hebei	Chloride emission standards	water	2007.01.01
DB13/1200-2010	Hebei	Emission standard of air granular matter for iron ore mineral processing factory	air	2010.05.04
DB13/1461-2011	Hebei	Steel industrial air pollutants emission standards	air	2011.11.30

Doc No.	Province	Document Title	Pollutant	E ective Date
DB23/1341-2009	Heilongjiang	Furfural industrial water pollutant discharge standards		2009.08.01
DB41/538-2008	Henan	Ammonia industry wastewater discharge standards	water	2009.01.01
DB41/681-2011	Henan	Beer industrial wastewater discharge standards	water	2011.11.01
DB41/684-2011	Henan	Lead smelting industry emission standards	water, air	2013.01.01
DB32/670-2004	Jiangsu	Discharge Standard of Water Pollutants for Dyeing and Finishing	water	2005.01.01
DB32/939-2006	Jiangsu	Discharge Standard of main water pollutants for chemical industry	water	2006.07.26
DB32/1072-2007	Jiangsu	Discharge Standard of Main Water Pollutants for Municipal Wastewater Treatment Plant & Key Industries of Taihu Area	water	2008.01.01
DB21/1627-2008	Liaoning	Integrated Wastewater Discharge Standard	water	2008.08.01
DB37/336-2003	Shandong	Wastewater discharge standards for paper industry	water	2003.05.01
DB37/533-2005	Shandong	Discharge Standard of Water Pollutants for Dyeing and Finishing	water	2005.05.01
DB37/534-2005	Shandong	Emission standards for livestock and poultry industries		2005.05.01
DB37/532-2005	Shandong	Cement industry emission standards of air pollutants	air	2005.07.01
DB37/597-2006	Shandong	Cooking fume emission standards		2006.01.04
DB37/664-2007	Shandong	Thermal power plant air pollutant emission standards	air	2007.05.01
DB37/676-2007	Shandong	Integrated Wastewater Discharge Standard in Shandong Peninsula Basin	water	2007.10.01
DB37/990-2008	Shandong	Iron and steel industry emission standards	water, air	2008.02.01
DB37/1919-2011	Shandong	Aluminum industry emission standards	air	2011.10.01
DB37/2376-2013	Shandong	Integrated Emission Standards of Air Pollutants	air	2013.09.01
DB37/595-2006	Shandong	Starch processing industrial water pollutant discharge standards	water	2006.01.04
DB31/373-2006	Shanghai	Discharge Standard of Pollutants for Bio-pharmaceutical Industry	water, air	2006.02.01
DB31/374-2006	Shanghai	Discharge Standards of Pollutants for Semiconductor Industry	water, air	2007.02.01
DB31/387-2007	Shanghai	Emission standard for air pollutants from boilers	air	2007.09.01
DB31/445-2009	Shanghai	Discharge Standard for Municipal Sewerage System	water	2009.09.01
DB31/199-2009	Shanghai	Integrated wastewater discharge standard	water	2009.10.01
DB31/373-2010	Shanghai	Discharge Standard of Pollutants for Bio-pharmaceutical Industry	water, air	2010.07.01
DB31/ 387-2013	Shanghai	Emission standard for air pollutants from boilers	air	2007.09.01
DB12/151-2003	Tianjing	Tianjin Emission Standard of air pollutants of gas- red boiler	air	2003.10.01
DB12/356-2008	Tianjing	Tianjin Integrated Wastewater Discharge Standard	water	2008.02.18
DHJB1-2001	Zhejiang	Discharge standard 1		

Appendix D - Pollution intensity by industry

Most water pollutant-intensive industries

COD Emissions (in kilos) per thousand yuan output

Industry	Average 1998-2000	Average 2001-2004	Average 2005-2008	Total Average
Papermaking and paper products	33.111	10.729	4.518	14.574
Agricultural and sideline foods processing	5.774	2.469	1.295	2.943
Water production and supply	3.524	2.823	2.380	2.853
Beverage production	3.558	1.823	0.880	1.953
Leather, furs, down, and related products	3.355	1.083	0.721	1.571
Food production	2.927	1.437	0.563	1.526
Chemical ber	2.124	0.980	0.594	1.152
Mining and Processing of Nonmetal Ores	1.743	1.039	0.708	1.111
Medical and pharmaceutical products	1.739	0.986	0.481	1.008
Mining and Processing of Non-ferrous Metal Ores	1.325	0.678	0.903	0.936
Fuel gas production and supply	0.845	0.544	1.326	0.911
Raw chemical material and chemical products	1.432	0.815	0.452	0.851
Textile industry	1.332	0.776	0.536	0.840

Ammonia Nitrogen Emissions (in kilos) per thousand yuan output

Industry	Average 1998-2000	Average 2001-2004	Average 2005-2008	Total Average
Fuel gas production and supply	.	0.168	0.387	0.278
Raw chemical material and chemical products	.	0.323	0.145	0.234
Water production and supply	.	0.165	0.209	0.187
Papermaking and paper products	.	0.192	0.103	0.147
Food production	.	0.176	0.069	0.122
Agricultural and sideline foods processing	.	0.120	0.069	0.095
Leather, furs, down, and related products	.	0.093	0.085	0.089
Mining and Processing of Nonmetal Ores	.	0.047	0.034	0.040
Petroleum processing, coking, and nuclear fuel processing	.	0.053	0.026	0.039
Beverage production	.	0.046	0.032	0.039
Medical and pharmaceutical products	.	0.037	0.031	0.034
Textile industry	.	0.033	0.028	0.030
Smelting and pressing of nonferrous metals	.	0.040	0.015	0.028

Petroleum Emissions (in kilos) per thousand yuan output

Industry	Average 1998-2000	Average 2001-2004	Average 2005-2008	Total Average
Water production and supply	0.067	0.031	0.012	0.034
Extraction of Petroleum and Natural Gas	0.037	0.016	0.007	0.019
Fuel gas production and supply	0.028	0.013	0.003	0.013
Smelting and pressing of ferrous metals	0.028	0.011	0.003	0.012
Petroleum processing, coking, and nuclear fuel processing	0.018	0.009	0.006	0.010
Raw chemical material and chemical products	0.022	0.009	0.003	0.010
Mining and Processing of Non-ferrous Metal Ores	0.013	0.005	0.001	0.006
Medical and pharmaceutical products	0.012	0.003	0.001	0.005
Ordinary machinery manufacturing	0.011	0.003	0.001	0.004
Chemical ber	0.008	0.003	0.001	0.004
Food production	0.003	0.001	0.005	0.003
Papermaking and paper products	0.007	0.002	0.001	0.003
Special equipment manufacturing	0.006	0.002	0.001	0.003

Most air pollutant-intensive industries

SO_2 Emissions (in kilos) per thousand yuan output

Industry water and air pollution intensity
(kilogram /000 RMB output)

	Industry	COD equivalent water pollution			SO2 equivalent air pollution		
		Average 1998-00	Average 2001-04	Average 2005-08	Average 1998-00	Average 2001-04	Average 2005-08
06	Mining and washing of coal	0.852	0.490	0.283	3.422	1.870	1.253
07	Extraction of petroleum and natural gas	0.518	0.295	0.155	0.330	0.187	0.242
08	Mining and processing of ferrous metal ores	1.062	0.568	0.301	7.185	3.483	1.676
09	Mining and processing of non-ferrous metal ores	2.292	1.013	1.168	3.472	1.387	2.715
10	Mining and processing of nonmetal ores	1.844	1.141	0.783	13.270	6.673	7.268
11	Mining of other ores	0.361	0.406	0.484	2.670	2.283	2.430
13	Agricultural and sideline foods processing	5.821	2.634	1.387	1.439	1.074	0.671
14	Food production	2.959	1.665	0.703	1.183	0.894	0.761
15	Beverage production	3.599	2.077	0.957	1.644	1.407	0.831
16	Tobacco products processing	0.099	0.045	0.016	0.144	0.104	0.081
17	Textile industry	1.355	0.827	0.568	1.202	0.951	0.783
18	Clothes, shoes, and hat manufacture	0.567	0.237	0.286	0.532	0.345	0.374

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