Spatial Development, Environmental Regulation and Productivity: The Porter Hypothesis Goes to China

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Abstract

We examine the relationship between environmental regulation and competitiveness in China. Exploiting changes in national pollution standards for three industries—ammonia, paper and cement—we test whether environmental regulation increases industry productivity. Our results show that the strong version of the Porter hypothesis does not hold, but that regulation might reallocate productivity spatially. We show that regulated industries that are located in developing cities see an increase in their productivity as compared to the same industries in other cities. This means that environmental regulation is more likely to drive the spatial distribution of productivity changes than it is to drive the pace and direction of technological change.

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1 Introduction

Much has been written about the relationship between regulation and firm competitiveness, ever since the seminal work by Michael Porter (Porter and Van der Linde (1995)). The Porter hypothesis states that one potential impact of environmental regulation might be to incentivise technological change, and so enhance production and efficiency in the regulated industries. In China, this relationship would appear to exist as well, as environmental regulation has been increasingly introduced over the course of China's economic development. This has resulted in technological change and regulation appearing to move together across the country's development trajectory (Xie et al. (2017), Wang and Shen (2016) and Zhang et al. (2011)).

In this paper, we study the relationship between these two phenomena with a focus on the institutional context of Chinese industry. Does the form that environmental regulation takes in China actually incentivise the pace and direction of technological change there? Or is there some other explanation for the way in which they are linked? To answer these questions, we examine the effect of national pollution standards on industry productivity for three industries. We find that environmental regulation has generated a spatial reallocation of productivity in the country rather than overall change in pace or direction. After regulation became effective, regulated industries in developing cities—that is, cities with low average firm productivity—experienced an increase in productivity as compared to the same industries in other cities. This seems to be caused more by the vintage of the capital these industries possess—which we assume to be proportional to industry productivity—than the regulation they are under.

China's unprecedented economic growth in the last decades has generated serious environmental problems. The central government has attempted to address this through a series of regulatory policies that began in the 1970s (OECD (2006)). In 1979, the state council first proposed that pollution charges should be written in the Environmental Protection Law. Later on, in 1982, it defined the basis for the pollution levy system that was implemented in the whole country in 1996, and that still exists today (Jiang et al. (2014)). Finally, in 2011, state council determined that environmental protection is also a criterion for promotion of local officials (Zheng and Kahn (2013)). Moreover, from 1996 to 2003, a series of new national pollution standards (NPS) for different products in several industries was published and made effective, regulating air and water emissions for most of China's manufacturing sector.[1]

But what is the effect of environmental regulation on economic de-

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[1] A list with these NPS can be found in the website of the Chinese Ministry of Environmental Protection.

velopment in China? According to the Porter hypothesis, environmental regulation might affect the pace and direction of technological change through innovation (Ambec et al. (2013)). Over the years, there have been many attempts to test this hypothesis empirically (Lanoie et al. (2011), Alpay et al. (2002), Becker (2011) and Berman and Bui (2001)). Unfortunately, however, most of these studies were conducted for developed countries, and results are still inconclusive. In China, particularly, there are great challenges to assess environmental regulation's effect on industry competitiveness. Although environmental regulation is defined nationally, each local authority, through their regional Environmental Protection Bureau, has autonomy to apply regulation according to local circumstances, such as economic development and institutional culture (Zheng and Kahn (2013)). This practice leads to a great range of regional and industrial variation in terms of enforcement, fees collected and certificates issued (Tilt (2007) and Wang et al. (2003)).[2] It is difficult to see how regulation of this quality is able to induce technological change.

Exploiting variations in the enactment of NPS, we test two different hypotheses. First, we test the strong version of the Porter hypothesis, that is, whether environmental regulation increases industry productivity. Second, we test whether environmental regulation increases productivity of regulated firms that are located in developing cities. We call this the spatial Porter hypothesis. Through a series of difference-in-differences (DID) regressions, we show that, although the Porter hypothesis does not hold, there are signs of the spatial Porter hypothesis in China. NPS have a positive effect on industry productivity in developing cities as compared to the same industries in other cities for ammonia, paper and cement industries. This means that environmental regulation probably changes the spatial distribution of technology in the country, more so than the direction of technology overall.

To interpret our results, we construct a tax competition model.[3] In our model, local governments compete for unskilled workers through variations in production taxes.[4] Tax reduction boosts economic output by creating incentives for firms to hire more workers, but also increases health costs that are proportional to local pollution levels. More stringent pollution standards increase health costs and force local government to set higher taxes. Because local governments are located in jurisdictions characterized by differing productivity levels, tax rates (and

[2]In fact, some authors argue that little effective enforcement has resulted (Zheng et al. (2014))

[3]This model is an adapted version of a more complete model that we present in Naso and Swanson (2017).

[4]We build on the tax competition literature, in the tradition of Zodrow and Mieszkowski (1986), Oates and Schwab (1988) and Bucovetsky (1991). We also use elements of the more recent studies in this literature (Bucovetsky (2009) and Janeba and Osterloh (2013)).

changes) are different across jurisdictions. The result is that, after environmental regulation is introduced, productive factors move from more to less developed jurisdictions, changing spatial economic development. Developing regions attract newer vintages of capital, and hence evince higher productivities, but this is an artifact of staged spatial development rather than induced technological change.

Our results contribute to two branches of the environmental economic literature. First, we contribute to the literature on the effects of environmental regulation on firm competitiveness (Lanoie et al. (2011), Becker (2011) and Greenstone et al. (2012)), testing the Porter hypothesis for the case of China. Second, we contribute to the nascent empirical literature on the unforeseen consequences of environmental regulation in developing countries (Duflo et al. (2013), Oliva (2015) and Hansman et al. (2015)). Our results shed light on the consequences of the design and implementation of regulation in an environment of imperfect institutions, and help to better understand how environmental regulation works.

The next section relates this paper to the existing literature regarding the Porter hypothesis, and describes how environmental regulation operates in China. Section 3 describes the theoretical framework we use to explain our results. Section 4 presents our data. In section 5 we present our empirical analysis. We conclude the paper in section 6.

2 Related Literature – the Porter Hypothesis in China

In line with our paper, most of the recent work on the Porter hypothesis—and, more specifically, on the relationship between productivity and environmental regulation—is concerned with testing it empirically. Despite early evidence suggesting that the hypothesis does not hold, two studies find a positive relationship between productivity and regulation. Berman and Bui (2001) show that refineries in Los Angeles have significantly greater productivity than in other areas of the U.S., despite a more stringent air pollution regulation. Alpay et al. (2002) find that productivity of Mexican food processing industry increases with environmental regulation.

However, more recent work, also for the U.S. economy, provides evidence that either there is no effect of regulation on productivity (Becker (2011)) or, if there is any effect, it is negative (Greenstone et al. (2012)). Lanoie et al. (2008) also find a negative impact of regulation on the TFP of manufacturing sectors but in Quebec, Canada. Two other recent studies examine the Porter hypothesis for a set of countries and do not find any statistically significant result. Rubashkina et al. (2015) use an IV

approach to examine the manufacturing sectors of 17 European countries between 1997 and 2009 to find no change in average productivity. And Lanoie et al. (2011) study 4,200 facilities in 7 OECD countries and find no evidence of the strong version of the Porter hypothesis. Building upon these recent empirical studies, we employ a DID specification to test whether NPS affect industry productivity in China.

To understand the impact of environmental regulation in China, it is important to understand a bit how environmental regulation operates there.

Chinese environmental regulation dates back to 1979, when the central government issued the first main piece of national environmental regulation, the Environmental Protection Law (EPL), which would only come into effect in 1989 (OECD (2006)). This law laid out general principles of environmental protection, described key instruments for environmental management, and specified which regulations should be enforced at the national and local levels (Jiang et al. (2014)). In 1988, the State Environmental Protection Agency (later replaced by the Ministry of Environmental Protection), which was responsible for the implementation of pollution charges, was created along with the Environmental Protection Bureaus (EPBs) (Tilt (2007)). The EPL also set the basis of the pollution levy system, which was implemented in the whole country in 1996 (Jiang et al. (2014)).

Although these measures indicated a willingness to reduce pollution emissions on paper, they were not followed through with real enforcement. The central government kept promoting local leaders according to their economic performance, regardless of the environmental consequences of their decisions (Zheng et al. (2014)). It was only more recently, beginning at the end of the 1990s, that the central government began to show serious—although timid—interest in mitigating China's air and water pollution levels. In 2003, new pollution charges covering almost all polluting elements were brought into effect. In 2011, the state council restated its concern that environmental protection should be a criterion for promotion of local officials (Zheng and Kahn (2013)). Moreover, from 1996 to 2013, a series of new NPS for different products in several different industries were published and made effective (Jiang et al. (2014)). They regulate air and water emissions for most of China's manufacturing sector.[5]

The pollution levy system is still in operation today and is the main tool for environmental regulation in the country (OECD (2006)). Over-standard discharges of waste water, waste gas and noise (since 1991) are subject to a levy—although the polluting firm is only required to pay on the sum of the highest three pollutant-specific levies, rather than levies for all pollutants (Jiang et al. (2014)). The levy collected is to be used

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[5]In this paper, we study the effect of three of these NPS on industry productivity.

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to finance environmental development, administration of the program, and to subsidize firms' pollution control projects (Wang et al. (2003)).

The amount of levies collected varies greatly in time and space, however (Tilt (2007)). There are two reasons for that. First, there are some differences in concentration standards used across provinces (OECD (2006)). Sometimes local and national governments decide together to apply differing pollution standards for a specific region. Besides that, some provinces can have extra regulation or stricter standards on specific pollutants. Second, and most importantly, part of the variation is due to differences in enforcement of regulation. In China, EPBs are responsible for inspecting and collecting levies from industrial facilities (Wang et al. (2003)). Each EPB has autonomy to enforce environmental regulation according to specific socioeconomic characteristics of its region (Tilt (2007) and Zheng and Kahn (2013)). Local authorities decide how much levies to collect and when, leading to a process that diverges considerably from what is written in the law.[6]

Two studies provide empirical evidence for this scenario. Wang and Wheeler (2000) show that collection of pollution levies is sensitive to differences in local economic development and environmental quality. Wang et al. (2003) find that state owned firms and firms in a bad financial situation have more bargaining power in levy payment than other firms.

In general, it seems that local governments use environmental regulation to protect local economic interests as much as for the protection against pollution levels. Levies and penalties can become another tool to accomplish local governmental objectives, such as attracting new firms to their regions or shutting down inefficient firms (Van Rooij and Lo (2010)).

What is the impact of such regulation on Chinese industry? There is a significant literature on the general effects. Jiang and McKibbin (2002) study how effective in controlling pollution the regulation systems used in the country are. Jin and Lin (2014) tests whether air pollution levy improves firms' technical efficiency—and finds no statistically significant effect. Jiang et al. (2014) examines firm-level emissions data and find that both foreign and domestic publicly-listed firms show less intensive pollutant emissions compared to state-owned enterprises. They also find that larger firms, firms in industries that export more, and firms with more educated employees tend to pollute less. Jefferson et al. (2013) find some evidence that environmental regulation induce pollution-intensive firms to improve economic performance. Lu et al. (2014) investigates how environment regulation affects foreign direct investment (FDI) and, using a DID approach, finds that there is a

[6]Evidence has also shown that some EPBs have been accused of corruption (Jiang et al. (2014)).

drop of 31.9% in FDI after enactment. Finally, Hering and Poncet (2014) study how exports from selected cities are affected by stricter regulation on sulfur dioxide and find a fall in exports after the introduction of regulation.

Despite this extensive list of studies, there is little effort at investigating how regulation has directed technological change and development. We address that gap here.

3   Theoretical Framework

In this section, we present an adapted version of the model developed in Naso and Swanson (2017).[7] Our model describes the spatial changes in production, workforce and productivity in an economy that operates within a federal regulatory structure.

The economy consists of several autonomous jurisdictions, each composed by a regulatory unit, a local government. Local governments in this federation compete to attract workers to their jurisdictions through variations in production taxes. Their objective is to maximize local tax revenue less health costs that are proportional to local pollution. The enactment of more stringent environmental regulation by the national government decreases local governments' tolerance towards pollution, and causes them to increase taxes. Because jurisdictions differ in terms of their productivity values—or vintage of capital—and local pollution is proportional to local productivity, local governments in more productive jurisdictions increase taxes more than governments in other places. This forces workers to migrate, and shifts production from the most to the least developed jurisdictions.

Our the model demonstrates how development might shift spatially in response to environmental regulation. The movement of workers shift output and pollution to developing jurisdictions, and increase effective productivity in these places.

3.1   A Tax Competition Model

Consider a national economy composed of N jurisdictions. Each jurisdiction is composed of a local firm and a local government. Local governments are organized in a federal structure, under a national government. They have autonomy to set production taxes in their jurisdictions.

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[7]We invite readers to look at Naso and Swanson (2017) for a more complete discussion on the validity of assumptions used in our model. In that paper, we study how environmental regulation affects spatial development in a broader sense—both in terms of changing the distribution of technology and in expanding it through the finance of new development zones (new jurisdictions).

Local firms can only employ local workers, L_i. There is no unemployment in our model, so local population of workers corresponds to total local population. We normalize national population to be equal to one, $\bar{L} = 1$.

Jurisdictions differ in terms of their vintage of immobile physical capital. Newer vintages enable firms to produce more goods than others for the same quantity of labor employed. Hence, jurisdictions that have a more productive vintage also have greater productivity, A_i.[8]

3.1.1 Firms, Workers and Local Governments

There are three types of agents in our model: firms, workers and governmental units.

Workers Workers maximize individual utility, $U(c_i)$, where c_i is consumption received in jurisdiction i. They have identical preferences and are mobile across jurisdictions, such that, in equilibrium we have:

$$U(c_i) = U(c_j) \; \forall \; i, j. \tag{1}$$

Since they consume exactly what they receive in wages, utility equalization implies wage equalization.

Firms There is one representative firm per jurisdiction that produces a common composite good with normalized price $p = 1$. Firms are immobile, and can only employ local workers. They are obliged to use local productivity—i.e. the available vintage of capital—A_i.

They have Cobb-Douglas technology such that output is given by

$$Y(A_i, L_i) = A_i(L_i)^{\alpha}, \tag{2}$$

where $0 < \alpha < 1$.[9] Firms have to pay local production taxes, τ_i, to local governments.[10]

They maximize profits subject to wages, w_i^r, local taxes and productivity, such that wages paid to local workers are:

$$w_i = (1 - \tau_i)\alpha A_i(L_i)^{\alpha - 1} \tag{3}$$

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[8]Immobile capital has been studied, for example, in Gordon and Bovenberg (1996), Sharma (2008) and Chan et al. (2011). These studies provide evidence that there is no perfect market integration for capital across political units, and, because of that, spatial differences in productivity might persist.

[9]We use a Cobb-Douglas type of production function for the sake of simplicity. Theoretical papers in the tax competition literature usually use quadratic production functions to derive numerical results (Bucovetsky (1991) and Bucovetsky (2009)).

[10]Local governments in China do not have much autonomy to set taxes, but they can offer tax rebates; and most of their revenue comes from fixed production taxes (Brys et al. (2013)).

When operating, firms emit pollution P_i, which is assumed to remain within their jurisdiction:

$$P_i = \eta Y_i. \tag{4}$$

Pollution levels increase as a fraction of local output. The constant $0 < \eta < 1$ is the coefficient of emissions per output.[11]

Local governments The local government of each jurisdiction has revenue that comes from tax collection from firms, $\tau_i Y_i$, and from the national government's transfer. It also has a health cost function, $\phi P_i L_i$, that is a function of local pollution and local population.

Local government's optimization problem is given by,

$$\underset{0 \leq \tau_i < 1}{\text{maximize}} \quad \tau_i Y_i - \phi(P_i - \bar{P})L_i, \tag{5}$$

where $\bar{P}$ is the national pollution threshold, which is established by the national government. The term $P_i - \bar{P}$ can be interpreted as the level of local tolerance towards pollution levels. Local governments maximize their revenue given health costs associated to pollution. A tax increase reduces health costs, but also revenue.

This setup of the local government objective function may be considered to be the net result of a federal incentive system that incentivises growth and production (e.g. via promotion of leaders) and penalizes excessive pollution and its health costs (e.g. via pollution levies).[12]

National government The national government establishes an ambient air standard theoretically applicable across all jurisdictions. It also enables transfers to local governments of resources meant to cover local health expenses.[13] This amount is assumed to be proportional to the local population and to the national pollution threshold, $\bar{P}$, established by the national government:

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[11]As in Stokey (1998), we assume that pollution is proportional to output produced. For the sake of simplicity, we assume that η does not vary across jurisdictions. This means that every jurisdiction has the same emissions technology (greater productivity does not imply greater environmental efficiency).

[12]The central government promotes or demotes local leaders on the basis of their economic performance (Wu (2010)), and uses GDP as the main evaluation criterion (Zheng et al. (2014)). This motivates our assumption that local governments seek to maximize the difference between tax revenue and health costs. Lower production taxes will boost local output, but will also increase pollution levels that will, eventually, damage the local working force.

[13]We assume that the national government taxes equally each local government to finance such health transfers. This tax is a fixed share of net local revenue, so we do not include it in the local governments' objective function.

$$R(\bar{P}, L_i) = \phi \bar{P} L_i, \tag{6}$$

The constant $0 < \phi < 1$ converts pollution units into health cost units.[14] [15]

3.2 The Game

Here we present an illustration of the way in which tax competition might occur between local governments within the above setup. This provides a basic picture of the way these local governments compete within this federation.

- **Players**: Local Governments;

- **Actions**: $\tau_i \in [0, 1)$;

- **Payoffs**: $\tau_i Y_i - \phi(P_i - \bar{P}) L_i$;

- **Time Structure**:

  – $t = 1$: N local governments set production taxes simultaneously;

  – $t = 2$: Workers migrate and wages are equalized.

Local governments seek to maximize tax revenue minus health costs, given firms and workers' behavior. After production taxes are set, migration of workers occurs and wages are equalized.

3.3 Results

The following proposition characterizes some features of the subgame perfect equilibrium of this game.

Proposition: For taxes set around zero, productivity values around an average A, and a large number of jurisdictions, we have that,

 i National Threshold: $\frac{\partial \tau_i}{\partial \bar{P}} < 0$;

 ii National Threshold and Productivity: $\frac{\partial^2 \tau_i}{\partial \bar{P} \partial A_i} < 0$;

iii Migration: $\frac{\partial L_i}{\partial \tau_i} < 0$.

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[14]There is substantial research showing that pollution generates health costs in China (Yang et al. (2013) and Chen et al. (2013)).

[15]We do not model the national government in this paper. We assume that $\bar{P}$ is exogenous to the problem we are analyzing here. See Naso and Swanson (2017) for an attempt to endogenize this variable.

Proof. See Appendix.

These three inequalities describe what happens to local population and workforce as a function of productivity when there is a change in the national pollution threshold. A decrease in the size of the transfer sent to local governments—that is, a more stringent environmental regulation—decreases local governments' tolerance towards pollution, and increases local taxes. This increase is greater in more developed jurisdictions, that is, jurisdictions with higher productivity values. Finally, an increase in taxes in jurisdiction i decreases its local population or workforce. Higher taxes decrease local wages and send workers away. Since output is an increasing function of workforce, higher taxes also decrease local production and pollution. Therefore, we have that more stringent environmental regulation moves workers and production from developed to developing jurisdictions.

The intuition for these results is that the equilibrium payoff of developing jurisdictions decreases faster with a reduction in local workforce than the payoff of developed jurisdictions. This happens because both local production and local pollution levels in developing jurisdictions are low when compared to other places. Local governments in developing jurisdictions want to attract as many workers as possible until pollution becomes a burden. Local governments in developed jurisdictions, on the other hand, already have substantial health costs before a reduction in the national threshold. Because of their high A_i, they benefit from some reduction in pollution, P_i.

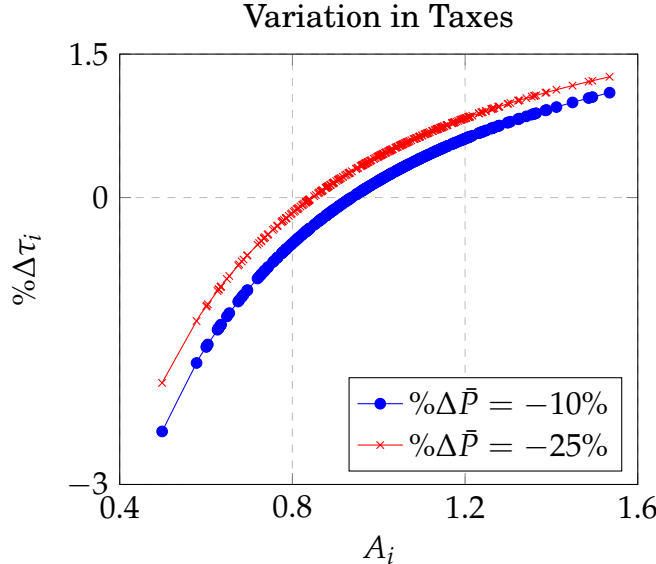Figure 1: Variation in Taxes as a function of Productivity

Figure 1 describes percentage changes in taxes as a function of ju-

risdictions' productivity after reductions of 10% and 25% in the national pollution threshold.[16] As described by our proposition, variation in taxes increases with jurisdictions' productivity. Local governments in developed jurisdictions increase taxes, whereas local governments in developing jurisdictions decrease taxes, when there is a reduction in $\bar{P}$. When we go from $\%\Delta\bar{P} = -10\%$ to $\%\Delta\bar{P} = -25\%$, the slope of the curve does not vary, but there is a parallel shift upwards. Local governments have to increase taxes more to compensate for a greater decrease in the national threshold.

Figure 2: Variation in Local Production as a function of Productivity
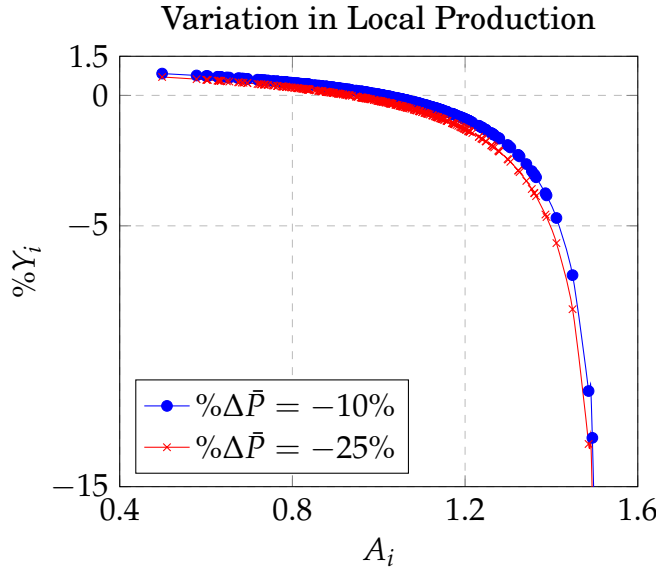
Figure 2 presents the dynamics of local production as a function of productivity after the national pollution threshold decreases. Local governments in jurisdictions with high productivity values decrease taxes and attract workers from developed jurisdictions to their localities. This change in workforce increases local production in the areas of this economy where productivity is low, and decrease local production in other places. Because the production function we use in our model is concave, increased workforce generates diminishing increases in output, and that is why we observe the slope presented in the figure. The result of this feature is an overall reduction in output of 0.34% and 0.65% for $\%\Delta\bar{P} = -10\%$ and $\%\Delta\bar{P} = -25\%$, respectively. Note that pollution is proportional to production. Pollution in developed jurisdictions decreases after $\bar{P}$ decreases, while there is an increase in developing jurisdictions.

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[16]We present parameter values of this simulation in the Appendix. No attempt has been made to calibrate our model. We are only interested in illustrating its qualitative dynamics.

One way to interpret this change in the distribution of output is to see it as a change in effective productivity. That is, how large the increase or decrease in local productivity would have to be, holding local workforce fixed, to reach the variation in local production that we observe after a reduction in the threshold. This variation in effective productivity is then exactly equal to the variation in output.[17] Developing jurisdictions increase effective productivity, whereas developed jurisdictions see a reduction in their effective productivity. Assuming that part of the additional output that comes from environmental regulation is transformed into immobile capital—and in increased local productivity—effective productivity is proportional to actual productivity when we abstract from the time dimension. Hence, through this perspective, a more stringent environmental regulation changes the distribution of technology in this economy.[18]

3.4 Discussion

The results of our model demonstrate that workers and production shift from more to less productive regions when more stringent environmental regulation is introduced. More stringent regulation changes the outcome of the tax competition game, increasing average taxes. However, the increase in taxes in developing jurisdictions is smaller than in developed ones. Workers then migrate from high to low productivity jurisdictions, and local production varies in proportion to this movement. Effective productivity follows output. At the end of this process, we observe technology moving to developing jurisdictions at a rate that is proportional to the stringency of regulation.

Therefore, the interaction between environmental regulation and imperfect institutions determines the spatial distribution of productivity in this economy, even though it has no impact in the direction or pace of

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[17]Initial local output is given by $Y_{0,i} = A_{0,i}(L_{0,i})^\alpha$. After the new threshold, $Y_{1,i} = A_{0,i}(L_{0,i} \cdot b)^\alpha$. We have that $Y_{1,i} = A_{0,i} \cdot b^\alpha (L_{0,i})^\alpha = A_{1,i}(L_{0,i})^\alpha$. Variation in productivity is then given by $\frac{A_{1,i} - A_{0,i}}{A_{1,i}} = b^\alpha - 1$.

[18]There are two ways to arrive at this conclusion. First, we can see the model we develop here as a simplified way to analyze changes in technology—in productivity or the vintage of immobile capital—generated by the introduction of environmental regulation. In this case, variations in workforce and output are just a tool to represent variations in productivity, and effective productivity is taken to be exactly equal to productivity and vintage of capital. The second way takes the model we construct more literally. The introduction of environmental regulation does move workers and production across jurisdictions, but there is no change in local productivity. The change in the distribution of technology comes with an extra step. If, for example, developing jurisdictions are able to transform part of the additional output that comes because of regulation into capital, productivity increases. Developed jurisdictions, on the other hand, lose part of their immobile capital, and their productivity. Effective productivity, in this case, is proportional to actual productivity.

technology itself.

4 Data

National Pollution Standards The piece of environmental regulation we use in our empirical analysis is the national pollution standards (NPS). The introduction of three new NPS in 2002 and 2005 is our *treatment*.

NPS were first established in 1996. They define emissions limits, monitoring requirements, standards of implementation and type of supervision of regulation for several different industries.

Table 1 details the specific NPS we use. In the second column, 'Doc Title', we see that they regulate three industries: ammonia, paper and cement industries. Note that these are broad industries that encompass several subindustries.[19] These are our *treated* industries. The third column of table 1 describes the pollutant these standards are controlling. Pollutants are chosen according to the nature of each of these industries. Paper and ammonia industries tend to emit more water pollution, whereas most pollutants of the cement industry come in the form of gases. The last column of the table specifies the effective date of each standard. These are the dates we use in our regressions—that is, *treatment dates*.

We choose these industries because of their relevance in the Chinese economy, and because of the amounts of pollution they emit. Ammonia, paper and cement are placed among the largest energy consumers and heaviest polluters of the country's economy.

Ammonia is an intermediate good, used mainly for the production of fertilizers. Due to its role in agricultural production and food security, the central government has undertaken a series of preferential policies for its development since the 1950s (Zhou et al. (2010)). Papermaking is one of the most water pollutant industries in China. The Chinese government has been concerned with pollution caused by this industry since, at least, 1994 (Yu et al. (2016)). Finally, since 1985, China has become the largest cement producer in the world (Wang et al. (2013)). This happened due to rapid industrialization and urbanization in the last decades.

Chinese Enterprises Database We work with the Chinese Industrial Enterprises Database (CIED) for the years 1998 to 2007. Its information comes from annual or quarterly reports that firms submit to

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[19]We present a full list of regulated industries—according to the 4-digit classification—in the Appendix. Chinese authorities use a 2-digit and a 4-digit classification codes to group firms into industry categories. We use the 4-digit classification, GB/T 4754-2011, to identify firms that belong to an industry.

the Chinese National Bureau of Statistics. The dataset includes detailed financial and operational information, such as total revenue and number of employees, for firms with sales above 5 million RMB per year— approximately U$ 813,000. It is a long unbalanced firm panel that takes up 90% of all enterprises in China—in proportion of sales (Nie et al. (2012))—and it has more than 2 million observations. Thus, we are focusing on medium and big firms in China. We do not have information on small firms—those that, for example, might be shut down because of excessive pollution or inefficiency.

Table 1: National Pollution Standards

Doc No.	Doc Title	Pollutant	Publication Date	Effective Date
GB13458-2001	Discharge standard of water pollutants for ammonia industry	water	12-Nov-2001	1-Jan-2002
GB3544-2001	Discharge standard of water pollutants for paper industry	water	12-Nov-2001	1-Jan-2002
GB4915-2004	Emission standard of air pollutants for cement industry	air	15-Dec-2004	1-Jan-2005

These are the three national pollution standards (NPS) we use in our regressions.

We only work with surviving firms, that is, firms that are present in every year of our panel. In total, we have 35,637 of these firms— and, hence, 356,370 observations. We do that to avoid unknown sample selection and to reduce measurement error.[20] Summary statistics for the main characteristics of the firms are presented in the Appendix.

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[20]The CIED experienced a great increase in coverage in more recent years. We do not exactly know the criteria used to include these new firms, and the quality of the figures they provide. Brandt et al. (2012), for example, support that coverage expansion is a result of an improvement in business registries of previously left firms. In that case, smaller firms with poor documentation would have been included, leading to increased noise in our sample.

In general, surviving firms are more productive and have better financial figures than others. They also tend to deal more easily with environmental regulation (through legal or illegal means). This might attenuate the effect of regulation on productivity as compared to the average firm in a given year. Thus, our choice on working only with surviving firms leads to a selection bias. However, we know the selected group better than other groups, and we can interpret our results accordingly.

To perform our empirical analysis, we construct a panel of industries in cities.[21] We calculate firm averages in each industry in a city in a year. In total, we have 813 industries and 377 cities.

We rank cities in China according to the average productivity of firms that operate in them. To do that, we construct a *city-productivity* distribution, with log productivity values for 1998.[22] Cities that have high average productivity in 1998 are called *developed*, while cities with low average productivity are called *developing*.

Finally, as a measure of productivity, we use total factor productivity (TFP).[23] TFP was calculated using firm level data from the CIED, according to the Olley-Pakes method. In line with the literature in the field, we find an increase in TFP over time for the period studied; from 2.02 to 3.21, approximately 5.89% per year (2.53% if we only take into account surviving firms).[24]

5 Empirical Analysis

In this section, we study the effects of NPS on industry productivity. We start by describing our identification strategy and by outlining our testable hypotheses. We then present two set of results. First, we show results for the standard Porter hypothesis. We show that there is no statistically significant effect of environmental regulation on average industry productivity for firms belonging to the ammonia, cement and paper industries. Second, we present our results for the spatial Porter hypothesis. We show that environmental regulation increases productivity of regulated industries in developing cities. We finish this section by examining possible mechanisms for this increase.

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[21]In China, cities are "the most basic decision-making units participating in the national and global economy" (Tao et al. (2016)).

[22]This distribution is plotted in the Appendix (figure 8).

[23]TFP and productivity will be used interchangeably from now on.

[24]Average TFP growth in the last decade in China is believed to be between 3.5% to 4.0% (Bosworth and Collins (2008), Chow and Li (2002), Holz (2006) and Perkins and Rawski (2008)).

5.1 Identification Strategy

We employ two different DID specifications that exploit cross-industry variation in NPS enactment to estimate the causal effect of environmental regulation on industry productivity.

Our identification strategy relies on two assumptions:

i In the absence of NPS, treatment and control groups would have parallel productivity trends;

ii Exogeneity of NPS enactment in relation to average industry TFP.

For each of our regressions, we try to show that the first assumption holds by plotting trends of TFP for control and treatment groups. When we use synthetic control groups, we construct these such that absolute differences in TFP pre-treatment between control and treated industries are minimized.

Exogeneity of NPS is not testable, but two suggestive arguments appear to show that this assumption also holds. First, examining the way national environmental regulation in China is drafted and approved, it seems unlikely that a specific industry in a specific city can foresee when its main product will be subject to regulation. NPS are turned effective by the central government, without much influence from authorities of smaller cities (OECD (2006)). Local governments may set more stringent standards, or they may create additional standards for pollutants that are not specified, but they are oriented to enforce national environmental regulation.

Second, a pooled probit regression on main average industry characteristics one year before environmental regulation shows that probability of an industry to be regulated is not correlated to TFP (see Appendix). This suggests that the central government is not looking specifically at the productivity of industries when enacting NPS.

A possible objection to our identification strategy is that the introduction of more stringent environmental regulation might be a function of average pollution of an industry. If this is true, and if industry productivity is somehow correlated to emissions intensity, then we might have a potential omitted variable bias—that is, our second assumption might not hold. To try to overcome this problem, we run all our regressions with a proxy for emissions intensity, the amount of physical capital used for production.[25]

5.2 Testable Hypothesis

We test two empirical hypotheses in this paper.

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[25]The results of the pooled probit regression show that physical capital is positively correlated to the probability of an industry to be regulated.

H1   The introduction of the NPS increases average industry productivity of regulated industries.

This is the strong version of the standard Porter Hypothesis. According to this hypothesis, national environmental regulation would be able to spur an increase in industry productivity. We show that this is not the case for China. NPS have no effect on average industry TFP for the three industries studied here.

H2   The introduction of the NPS increases average industry productivity of regulated industries in developing cities.

We call this the spatial Porter hypothesis. We show that national environmental regulation has the effect of reallocating productivity spatially in China. This means that regulated industries that are located in developing cities—that is, in cities where average productivity is low—experience an increase in their TFP.

5.3   Standard Porter Hypothesis

We begin by testing H1. The econometric specification we choose is

$$log(TFP_{it}) = \gamma_i + \lambda_t + \delta_i \cdot (reg_i \cdot post_t) + X_{it}'\theta + \epsilon_{it}, \tag{7}$$

where TFP_{it} is average TFP of industry i at year t. reg_i is a dummy for treated industries (ammonia, cement and paper), and $post_t$ is a dummy for year of treatment.

X_{it} is a vector of seven controls: log of physical capital, proportion of state owned firms in a industry, proportion of firms located in a special economic zone, log of age of average firm, log of current assets, log of number of employees, and log of sales' revenue.[26] These variables control for emissions intensity, type of ownership, size, location, and other firm characteristics that might be correlated to both productivity and environmental regulation.

We include two levels of fixed effects, γ_i and λ_t, respectively industry and year. Standard errors are clustered by industry. The interaction term, $reg_i \cdot post_t$, equals 1 for treated industries after year of treatment.

Our variable of interest is δ_i, which measures the effect of the introduction of NPS on average industry productivity of treated industries. For H1 to hold, we need δ_i to be positive and statistically significant.

We run one regression for each studied industry. We construct control groups in the following way. We calculate squared differences of log TFP

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[26]Our control variables remain the same for all regressions we run in this paper.

between treated and other industries for every year before treatment. We then plot the distribution of the square root of the sum of these differences. Control industries are the ones for which differences lie below the 5th percentile of this distribution.[27]

Table 2: DID of NPS on TFP of treated industries

	(1)	(2)
Ammonia		
δ_a	0.093	-0.035
	(0.068)	(0.046)
Controls	No	Yes
Year and Ind FE	Yes	Yes
Obs	7,925	7,866
R^2_{adj}	0.25	0.49
Paper		
δ_p	0.011	-0.026
	(0.029)	(0.038)
Controls	No	Yes
Year and Ind FE	Yes	Yes
Obs	8,304	8,238
R^2_{adj}	0.24	0.50
Cement		
δ_c	-0.036	-0.028
	(0.038)	(0.022)
Controls	No	Yes
Year and Ind FE	Yes	Yes
Obs	7,802	7,753
R^2_{adj}	0.21	0.45

Our dependent variable is log TFP per worker in an industry at a year.
Standard errors are clustered by industry.
We present adjusted R^2.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 2 presents our results. Estimates for all industries are statistically insignificant. This suggests that NPS do not have any effect on industry TFP, and that H1—the standard Porter hypothesis—does not hold for these industries and this set of environmental regulation in China.[28] As we mention in section 2, this result can be explained by

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[27]Figure 9 in the Appendix shows TFP trends for treated and control groups for each regression.

[28]It is possible to verify empirically, for the three industries analyzed here, a vintage

the nature of environmental institutions in China. The introduction of environmental regulation is not followed by enforcement by local authorities. Because of that, regulation does not generate any constraints on firm behavior, and productivity does not change.[29]

5.4 Spatial Porter Hypothesis

We now analyze the spatial effect of environmental regulation on industry productivity. We show in this section that there is evidence that supports that H2, the spatial Porter Hypothesis, holds for all three industries, ammonia, paper and cement.

Figure 3 shows log of average TFP for our treated industries in the main 344 cities in China. To construct this picture, we aggregated TFP averages in 1998 (left side) and 2007 (right side) for each city and industry. For example, in 1998, the average log TFP of firms belonging to the paper industry (red) located in Shanghai was equal to 0.95, approximately. Ammonia is depicted in blue, paper in green, and cement in red. Darker colours mean greater TFP.

The picture describes the spatial impact of NPS on productivity. We see that there is an increase in the TFP of treated industries located in the interior of the country over the years when compared to coastal cities. In 1998, cities in the Southeast region of China (Fujian and Guangdong provinces, mainly) concentrated the greatest average TFPs in China for the industries studied here. In 2007, after the introduction of NPS, this concentration dispersed to inland cities. This effect is particularly marked for the case of ammonia and paper.

To test whether this change in the spatial distribution of TFP is in fact generated by the introduction of NPS, we run two sets of regressions. We begin by defining two types of cities. *Developing cities* are cities that have an average TFP (including all industries that are present in each city) below the 25th percentile of the 1998 city-productivity distribution; cities above the 25th are defined as *developed*.

In our first set of regressions we fix industry type, and compare firms belonging to treated industries in different cities. We run the following regression,

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capital effect, that is, that the ratio between TFP growth and physical capital growth has been increasing over time. This suggests that the vintage of capital matters for TFP.

[29]This is one way to interpret our results. A possible explanation is that the Porter hypothesis does not hold in general, that is, environmental regulation does not affect firm productivity even when there is enforcement. Given the nature of environmental institutions in China, and previous empirical work done to test the Porter Hypothesis, we believe our interpretation is the one that best explains our results.

$$log(TFP_{ict}) = \gamma_{ic} + \lambda_{tc} + \mu_{it} + \delta_{i,25th} \cdot (post_t \cdot \underline{TFP}_c^{25th,1998}) + X'_{ict}\theta + \epsilon_{ict}, \tag{8}$$

where TFP_{ict} is average TFP of industry i in city c at year t; X_{ict} is a vector of seven controls.[30] We include three levels of fixed effects: industry-city, year-city and industry-year (γ_{ic}, λ_{tc} and μ_{it}).[31] The interaction term, $treated_i \cdot post_t \cdot \underline{TFP}_c^{25th,1998}$, is equal to 1 for treated industries in developing cities after the year of treatment, and zero otherwise. Standard errors are clustered by city.

Figure 3: Average TFP in 1998 and 2007
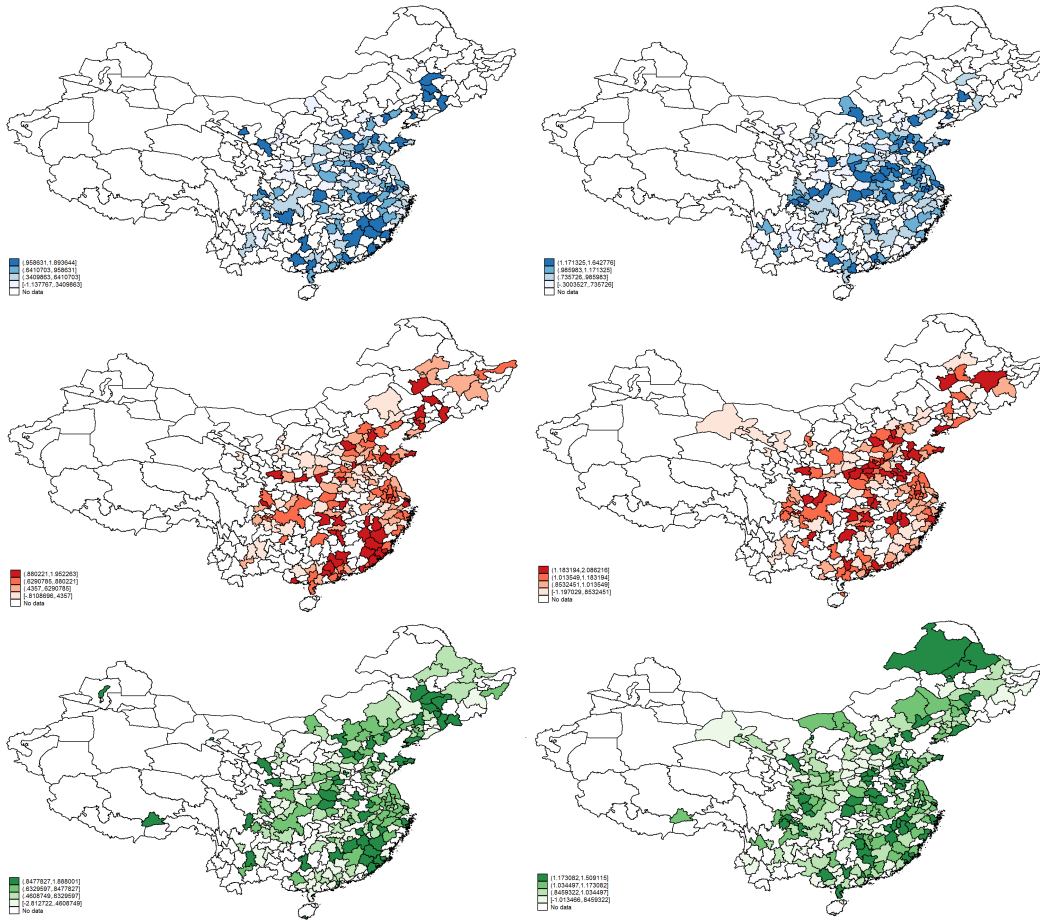
Average TFP for treated industries in the main 344 cities in China in 1998 (left) and 2007 (right). Ammonia (blue), Paper (red) and Cement (green). Cities with darker colors have greater average TFP.

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[30]The controls are: log of physical capital, proportion of state owned firms in a industry, proportion of firms located in a special economic zone, log of age of average firm, log of current assets, log of number of employees, and log of sales' revenue.

[31]We use the algorithm developed in Guimarães and Portugal (2009) to run our regressions.

Results are presented in table 3. They suggest that NPS increase average TFP of the cement industry in developing cities in approximately 5% when compared to the same industries in developed cities. This result is robust to tests with placebo regressions with random treatment dates. We do not have statistically significant results for ammonia and paper.

One potential problem of this first specification is that control and treatment groups might not have comparable dynamics. In China, industries are classified according to what they produce. Thus, when we fix the type of industry in our regression, we make sure that the nature of the output is the same across observations. However, because of great geographic differences, firms situated in developed cities might be able to access better infrastructure and technology than similar firms in developing cities. If these differences are too big, the nature of operation between treatment and control groups changes, and productivity dynamics is not comparable anymore.

Table 3: NPS on Treated Industries in Different Cities

|	
$\delta_{a,25th}$	0.029
	(0.044)
Controls	Yes
Fixed Effects	Yes
Obs	2,265
R^2_{adj}	0.50
$\delta_{p,25th}$	0.052
	(0.028)
Controls	Yes
Fixed Effects	Yes
Obs	2,804
R^2_{adj}	0.57
$\delta_{c,25th}$	0.050*
	(0.024)
Controls	Yes
Fixed Effects	Yes
Obs	3,606
R^2_{adj}	0.53

Our dependent variable is log TFP of an industry in a city at a year.
Standard errors are clustered by city.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

In fact, when we look at log TFP trends before NPS enactment for our three industries (see figure 10 in the Appendix), we see that trends

are only clearly parallel for the cement industry. Control and treatment groups for ammonia and paper do not seem to have parallel trends.

Our second set of regressions tries to correct for this problem by constructing synthetic control groups—the same way we do for the Standard Porter Hypothesis regression.[32] Figure 11 in the Appendix shows log TFP trends for treated industries and the new control groups we create.

Our new regression is now given by,

$$
log(TFP_{ict}) = \gamma_{ic} + \lambda_{tc} + \mu_{it} + \delta_i \cdot (ind_i \cdot post_t \cdot \underline{TFP}_c^{25th,1998}) + \\
X'_{ict}\theta + \epsilon_{ict}, \tag{9}
$$

where TFP_{ict} is average TFP of industry i in city c at year t; X_{ict} is a vector of seven controls.[33] We include three levels of fixed effects: industry-city, year-city and industry-year (γ_{ic}, λ_{tc} and μ_{it}). The interaction term, $ind_i \cdot post_t \cdot \underline{TFP}_c^{25th,1998}$, is equal to 1 for treated industries in developing cities after the year of treatment, and zero otherwise. Standard errors are clustered by city and industry.

Table 4 presents our results. We observe an increase in TFP that seems to be generated by environmental regulation for all three industries studied here. NPS increase average productivity of ammonia firms in 5%, of paper firms in roughly 8%, and of cement firms in 5%—in line with our previous result.[34]

The next step in our empirical analysis is to investigate the effect of the introduction of NPS in each segment of the city-productivity distribution. According to our theoretical model, regulated industries located in the very bottom of the distribution would experience greater productivity increases when compared to the same industries in slightly more productive cities. To test whether this happens, we rerun our last specification for each industry with three interaction terms instead of one: $ind_i \cdot post_t \cdot \underline{TFP}_c^{10th,1998}$, $ind_i \cdot post_t \cdot \underline{TFP}_c^{25th,1998}$ and $ind_i \cdot post_t \cdot \underline{TFP}_c^{50th,1998}$. These terms divide the city-productivity distribution in three groups, below the 10th percentile, between the 10th and 25th, and be-

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[32]We calculate squared differences of log TFP between treated industries in developing cities, $\underline{TFP}_c^{25th,1998}$, and non-treated industries in all other cities in China. With the distribution of these differences pre-treatment in hand, we select industries in cities for which the difference lies below the 5th percentile. Note that our control groups are composed of industries that are not regulated and are located in developed cities.

[33]The controls are: log of physical capital, proportion of state owned firms in a industry, proportion of firms located in a special economic zone, log of age of average firm, log of current assets, log of number of employees, and log of sales' revenue.

[34]We run placebo regressions with an arbitrary date of treatment to test these estimates, but results are inconclusive. For most of the cases, the coefficient of interest in our placebo regression is statistically insignificant, but there are some cases in which the coefficient is positive and statistically significant.

tween the 25th percentile and the median. We assume that the coefficient of interest remains constant in between percentiles.

Table 4: NPS on Treated Industries with new control groups

$\delta_{a,25th}$	0.053**
	(0.023)
Controls	Yes
Fixed Effects	Yes
Obs	3,924
R^2_{adj}	0.60
$\delta_{p,25th}$	0.078***
	(0.028)
Controls	Yes
Fixed Effects	Yes
Obs	4,384
R^2_{adj}	0.66
$\delta_{c,25th}$	0.051**
	(0.024)
Controls	Yes
Fixed Effects	Yes
Obs	4,843
R^2_{adj}	0.62

Our dependent variable is log TFP of an industry in a city at a year.
Standard errors are clustered by city and industry.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Results are presented in figure 4. Paper is the only industry that clearly follows the pattern we describe in our model. Firms belonging to this industry that are located in the bottom and middle of the distribution have an increase of roughly 9% in TFP. There is no statistically significant effect in firms near the median. We do not observe the same pattern for ammonia. In fact, there is no statistically significant effect at the very bottom of the distribution for this industry, and an almost constant 10% increase in TFP everywhere else. Finally, all estimates are statistically insignificant for cement at the 10% level. The combined effect in the bottom 25th that we observe in our previous regression vanishes here.

Figure 4: NPS on TFP: different percentiles
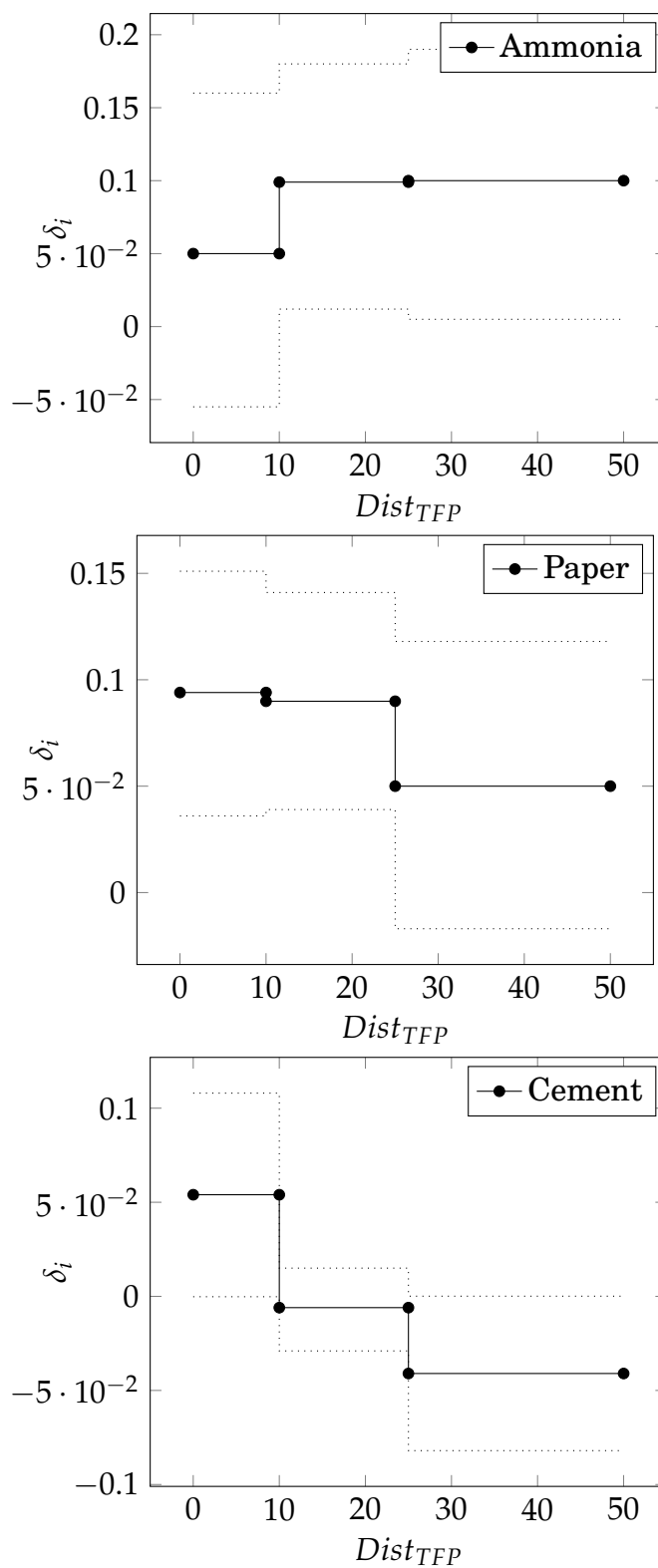
We present the coefficient for different percentiles of the city-productivity distribution in 1998. Dashed lines are 90% confidence intervals. We assume that coefficients are constant between percentiles. Standard errors are clustered by city and industry.

Overall, our results appear to confirm that the enactment of environmental regulation increased average productivity of regulated firms in developing cities in all three industries studied here. This is evidence in favor of our second testable hypothesis, the spatial Porter hypothesis. It seems that regulation triggered a process of technological reallocation across China. Productivity shifted from cities in the coast—usually more developed—to inland cities. Therefore, combining the results for our both hypotheses, we have that environmental regulation does not affect the pace and direction of technological change, but drives the spatial distribution of technology.

5.5 Taxes, Workforce and Output Dynamics

Our model conjectures that productivity increases in developing cities after the introduction of environmental regulation by virtue of migration of workers. Local authorities compete for workers through production tax, and local output increases as a function of local labour force. Hence, if the mechanism we propose is right, we would be able to observe variations in taxes, followed by variations in workforce, output and productivity.

In this section, we briefly describe what happens to taxes, workforce and output before and after the introduction of NPS.

Figure 5: Tax variation
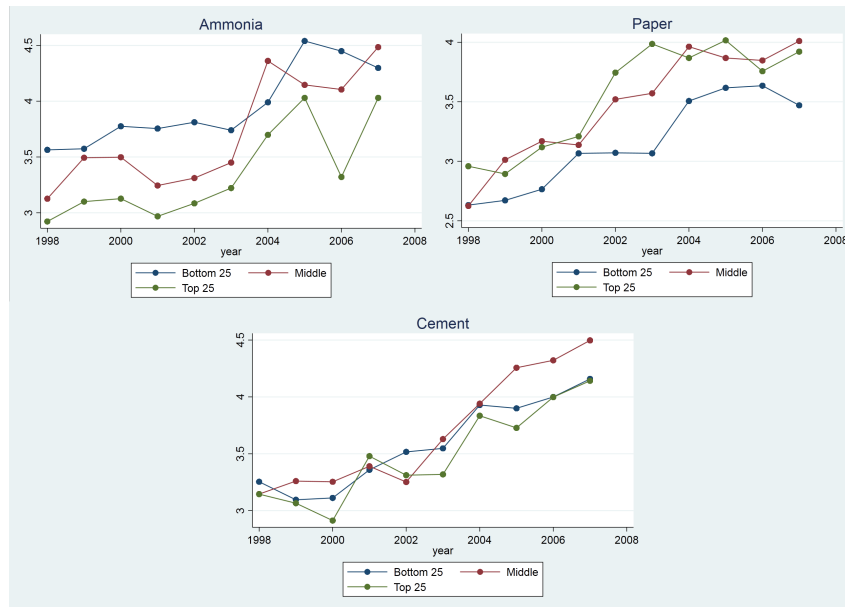
This figure depicts what happened to log of average declared taxes in treated industries before and after NPS in the bottom, middle, and top of the city-productivity distribution.

Average declared taxes of treated industries in the bottom, middle, and top of the city-productivity distribution are plotted in figure 5. We see a clear increasing trend in taxes after NPS (2002) for the top and the middle of the distribution for ammonia and paper. Firms belonging to the bottom experience a decrease—ammonia—or no change—paper—in average taxes. This is evidence in line with the theory we develop in this paper. We do not observe a similar pattern for the cement industry, however. Average taxes of all segments of the distribution increase after NPS (2005) for that industry at almost the same rate—although the increase is slightly greater for the top.

Figure 6: Workforce variation
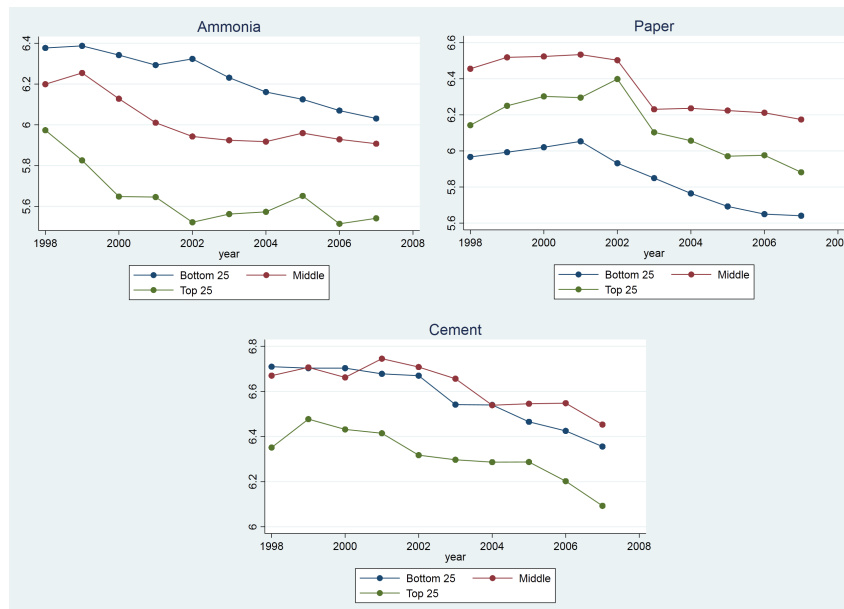
This figure depicts what happened to log of average number of employees in treated industries before and after NPS in the bottom, middle, and top of the city-productivity distribution.

According to our model, an increase in taxes generates a reduction in workforce. This happens, of course, if the labour market is perfectly competitive and if there are no frictions, such as transportation costs. In figure 6 we plot average number of employees of firms.

As we observe in all graphs, there is a general trend of reducing the average workforce in all industries and segments of the distribution. However, firms of the paper industry, located in the top, experience a substantial reduction in average workforce one year after NPS. This suggests that environmental regulation, and the increase in taxes we observe in the previous graph, might have generated this variation.

A similar effect is observed in the bottom and top of the cement industry in the period 2005-2006. There is no variation in average workforce

of firms located in the middle of the distribution, however. Ammonia does not present any particular pattern that can confirm our theory.

The last figure of this section describes what happens to average output before and after environmental regulation is introduced in China. Note that there is almost no significant variation over the years for ammonia and cement. Output for the paper industry increases in all segments of the city-productivity distribution after NPS (2002). But the increase is greater for the top and the middle—which is not in line with our model.

Figure 7: Output variation
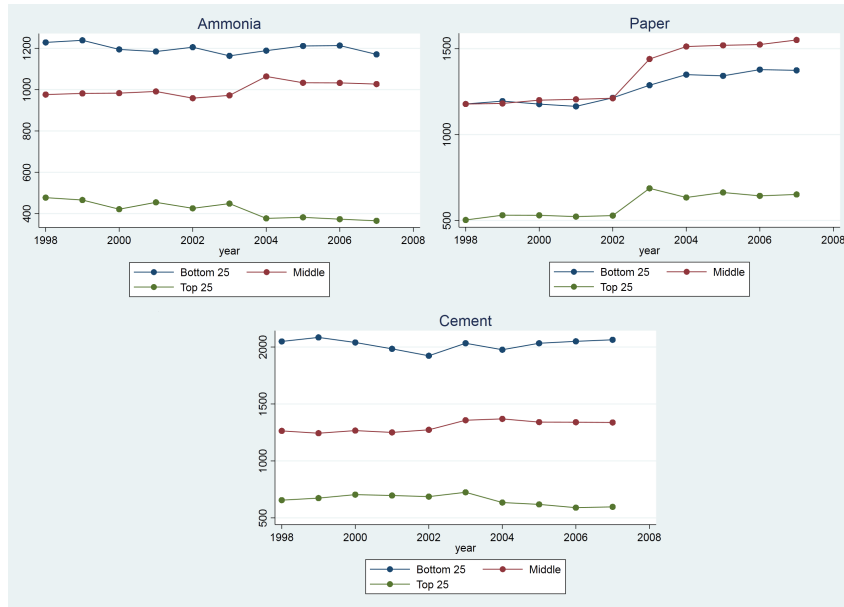
This figure depicts what happened to the log of average output in treated industries before and after NPS in the bottom, middle, and top of the city-productivity distribution.

Although it is not possible to infer any causal links between NPS and the variables presented in this section just by analyzing trends, the evidence we present here suggests that, at least for the paper industry, the mechanisms of our model might have played a role in reshaping the spatial distribution of productivity. Evidence is less clear for the case of ammonia and cement.

6   Concluding Remarks

Productivity growth and the implementation of environmental regulation have both been increasing since the 1970s in China. This positive correlation suggests that firms have been able to use regulation to increase their productivity—a process similar to what the Porter hypothesis postulates. We show in this paper, however, that this is not the case.

For the industries analyzed here, the strong version of the Porter hypothesis does not hold. Environmental regulation does not change the pace and direction of productivity change. However, we find that environmental regulation affects the spatial distribution of productivity. Regulated firms located in developing cities have their productivity increased after regulation is introduced. This is evidence for what we define as the spatial Porter hypothesis. Environmental regulation seems to shape spatial patterns of technology in the country.

The theoretical framework we use in this paper offers an explanation for the effect of environmental regulation on the spatial distribution of productive factors in the country. Local governments in all jurisdictions compete for unskilled workers through production taxes. Lower taxes attract migrants and increase local output, that, in turn, also increases local pollution. When the national government sets a more stringent national environmental regulation, local governments increase taxes. However, taxes increase at different rates, depending on the vintage of immobile capital—which is proportional to local productivity. Local governments in jurisdictions where productivity is high set greater taxes than jurisdictions with low productivity. This difference makes workers and output to shift from the most to the least productive regions in the economy, and changes the spatial distribution of productivity.

We are not able to test whether the mechanisms we propose in our model played a role in the changes we observe in the spatial distribution of productivity in China. But we provide some evidence suggesting that taxes and migration—at least for the paper industry—might have contributed to productivity increases in developing cities.

7 Appendix

7.1 Proof of Proposition

(i) We start by the firm maximization problem, and wage equalization:

$$\underset{L_i}{\text{maximize}} \quad (1 - \tau_i)Y_i - w_i L_i \tag{10}$$

F.O.C.: $w_i = (1 - \tau_i)\alpha A_i (L_i)^{\alpha-1}$. By the fact that workers are completely mobile, we have that, $w_i = w_j \ \forall i, j$. Given that total population is normalized to 1, we have that:

$$L_i = \frac{1}{1 + \sum\limits_{j=1}^{N-1} \left(\frac{A_i(1-\tau_i)}{A_j(1-\tau_j)} \right)^{\frac{1}{\alpha-1}}} \tag{11}$$

The derivative of this expression with respect to τ_i is negative, $\frac{\partial L_i}{\partial \tau_i} = \frac{L_i(1-L_i)}{(\alpha-1)(1-\tau_i)} < 0$.

(ii) From local government i's F.O.C., we have that:

$$\tau_i \leq \frac{\phi(1+\alpha)\eta L_i}{\alpha} - \frac{\phi \bar{P} L_i}{\alpha Y_i} - \frac{(\alpha-1)(1-\tau_i)}{\alpha(1-L_i)}, \tag{12}$$

Taking the derivative of this expression with respect to $\bar{P}$, and assuming that we are in a situation where the right hand side of this expression is greater or equal to zero, we have that,

$$\frac{\partial \tau_i}{\partial \bar{P}} E_1 = \frac{\partial L_i}{\partial \bar{P}} E_2 - E_3. \tag{13}$$

From the wage equalization equation, we have that,

$$L_j = \left(\frac{A_i(1-\tau_i)}{A_j(1-\tau_j)} \right)^{\frac{1}{\alpha-1}} L_i. \tag{14}$$

Taking the derivative of this expression with respect to $\bar{P}$, we have that,

$$\frac{\partial L_j}{\partial \bar{P}} = \frac{\partial L_i}{\partial \bar{P}} F_1 - \frac{\partial \tau_i}{\partial \bar{P}} F_2 + F_3 \frac{\partial \tau_j}{\partial \bar{P}}. \tag{15}$$

Taking the derivative of equation (11) with respect to $\bar{P}$, we have that,

$$\frac{\partial L_i}{\partial \bar{P}} G_1 = \frac{\partial \tau_i}{\partial \bar{P}} G_2 + \sum_{j=1}^{N-1} \frac{\partial \tau_j}{\partial \bar{P}} G_j. \tag{16}$$

Finally, we take the derivative of $\sum_{i=1}^{N} L_i = 1$ with respect $\bar{P}$, and have that,

$$\frac{\partial L_i}{\partial \bar{P}}\left(G_1 + \sum_{j=1}^{N-1} G_j \frac{F_1}{F_3}\right) = \frac{\partial \tau_i}{\partial \bar{P}}\left(G_2 + \sum_{j=1}^{N-1} G_j \frac{F_2}{F_3}\right) + \sum_{j=1}^{N-1} \frac{\partial L_j}{\partial \bar{P}} G_j \frac{1}{F_3}. \quad (17)$$

Then, if we work with these four equations, we can isolate the term $\frac{\partial \tau_i}{\partial \bar{P}}$. Analyzing this term around $\tau_i = 0 \; \forall i$, and $A_i = A \; \forall i$, and assuming N is very large ($N \gg A$), we have that,

$$\frac{\partial \tau_i}{\partial \bar{P}}\Big|_{\tau_i=0, A_i=A} < 0. \quad (18)$$

(iii) To examine the derivative $\frac{\partial^2 \tau_i}{\partial A_i \partial \bar{P}}$, we first need to calculate $\frac{\partial \tau_i}{\partial A_i}$.

Again, we differentiate expression (12) with respect to A_i and A_j, and obtain,

$$\frac{\partial \tau_i}{\partial A_i} H_1 = \frac{\partial L_i}{\partial A_i} H_2 + H_3, \quad (19)$$

$$\frac{\partial \tau_i}{\partial A_j} I_1 = \frac{\partial L_i}{\partial A_j} I_2. \quad (20)$$

We differentiate expression (14) with respect to A_i, and we have that,

$$\frac{\partial L_j}{\partial A_i} = \frac{\partial L_i}{\partial A_i} J_1 - \frac{\partial \tau_i}{\partial A_i} J_2 + J_3 \frac{\partial \tau_j}{\partial A_i} + J_4. \quad (21)$$

Finally, differentiating expression (11) with respect to A_i, we have that,

$$\frac{\partial L_i}{\partial A_i} K_1 = \frac{\partial \tau_i}{\partial A_i} K_2 + \sum_{j=1}^{N-1} \frac{\partial \tau_j}{\partial A_i} K_j - K_3 \quad (22)$$

Then, using these four equations, we isolate the term $\frac{\partial \tau_i}{\partial A_i}$. Analyzing this term around $\tau_i = 0 \; \forall i$, and $A_i = A \; \forall i$, and assuming N is very large ($N \gg A$), we have that,

$$\frac{\partial \tau_i}{\partial A_i}\Big|_{\tau_i=0, A_i=A} > 0. \quad (23)$$

That is, jurisdictions with higher productivity set higher taxes. Then, taking the derivative of this expression with respect to $\bar{P}$, we have that,

$$\frac{\partial}{\partial \bar{P}}\left(\frac{\partial \tau_i}{\partial A_i}\Big|_{\tau_i=0, A_i=A}\right) < 0. \quad (24)$$

Table 5: Descriptive Statistics for Surviving and Non-surviving firms

Year	Pollution Int.	Surv.	Exit	TFP Surv.	Exit	Employees Surv.	Exit	Ownership	Surv.	Exit
1998	High	0.18	0.16	2.38	1.76	544	196	state	0.26	0.27
	Medium	0.22	0.30	(1.46)	(2.22)	(3,028)	(865)	private	0.52	0.55
	Low	0.60	0.54					other	0.22	0.18
1999	High	0.18	0.16	2.27	1.48	584	223	state	0.25	0.26
	Medium	0.22	0.27	(1.12)	(1.96)	(2,746)	(1,284)	private	0.53	0.57
	Low	0.60	0.57					other	0.22	0.17
2000	High	0.18	0.16	2.36	1.59	577	225	state	0.23	0.23
	Medium	0.22	0.28	(1.15)	(2.01)	(2,537)	(997)	private	0.56	0.62
	Low	0.60	0.56					other	0.21	0.15
2001	High	0.18	0.15	2.44	1.66	562	183	state	0.21	0.22
	Medium	0.22	0.28	(1.14)	(2.13)	(2,418)	(714)	private	0.58	0.63
	Low	0.60	0.57					other	0.21	0.15
2002	High	0.18	0.15	2.56	1.79	562	206	state	0.20	0.21
	Medium	0.22	0.27	(1.11)	(2.18)	(2,393)	(867)	private	0.59	0.64
	Low	0.60	0.58					other	0.21	0.15
2003	High	0.18	0.17	2.65	2.36	569	218	state	0.20	0.14
	Medium	0.22	0.26	(1.13)	(1.72)	(2,344)	(855)	private	0.59	0.74
	Low	0.60	0.57					other	0.21	0.12
2004	High	0.19	0.13	2.68	2.38	561	149	state	0.18	0.15
	Medium	0.22	0.22	(1.18)	(1.95)	(2,324)	(637)	private	0.61	0.72
	Low	0.59	0.65					other	0.22	0.13
2005	High	0.19	0.15	2.79	2.51	586	152	state	0.17	0.09
	Medium	0.22	0.25	(1.23)	(1.80)	(2,556)	(472)	private	0.62	0.75
	Low	0.59	0.60					other	0.21	0.16
2006	High	0.19	0.16	2.90	2.54	586	144	state	0.16	0.15
	Medium	0.22	0.27	(1.23)	(1.93)	(2,635)	(475)	private	0.62	0.69
	Low	0.59	0.57					other	0.22	0.16
2007	High	0.19	0.16	2.98	3.08	579	203	state	0.15	0.05
	Medium	0.22	0.24	(1.30)	(1.48)	(2,610)	(962)	private	0.63	0.83
	Low	0.59	0.60					other	0.22	0.12

Descriptive statistics for surviving and non-surviving (exit) firms. Pollution intensity was calculated using information from the MEP. All the other values in this table were calculated using our dataset. Standard deviations are in parentheses.

7.2 Pooled Probit

Table 6: Pooled probit regression

	Average Margins	(Std. Err.)
Ownership		
State Owned$_{it-1}$	-0.0601**	(0.0244)
Private Owned$_{it-1}$	-0.0374*	(0.0210)
Foreign Owned$_{it-1}$	-0.2260***	(0.0444)
Location		
Special Economic Zone$_{it-1}$	0.0212	(0.0295)
Productivity$_{it-1}$	-0.0048	(0.0046)
Employees$_{it-1}$	-0.0232***	(0.0061)
Physical Capital$_{it-1}$	0.0255***	(0.0054)
Output$_{it-1}$	0.0354**	(0.0180)
Revenue$_{it-1}$	-0.0135	(0.0178)
Age$_{it-1}$	0.0036	(0.0056)
Assets$_{it-1}$	-0.0344***	(0.0067)
Obs	4,481	

Our dependent variable is the probability of an industry to be regulated. Dependent variables are industry averages one year before regulation.
Robust standard errors.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

7.3 Simulation: parameter values

Table 7: Parameter values for the Simulation

| Parameter	Value	Description
N	300	Number of Jurisdictions
$\bar{L}$	1	Total Population
Production Parameters		
A	$\mathcal{N}(1, 0.2)$	Distribution of Productivity
α	0.35	Labour elasticity
Environmental Parameters		
η	0.2	Emissions per output (intensity)
ϕ	0.7	Health Costs per Pollution Emitted
$\bar{P}$	1	National Threshold

No attempt has been made to calibrate the model. The simulation serves only as an illustration to the model we develop. To present our results, we linearize the system of equations around $\tau_i = 0 \ \forall i$, and $A_i = A \ \forall i$. We use the function lsqlin in Matalab to solve the system.

## Figure 8: Log TFP distribution of Chinese cities in 1998
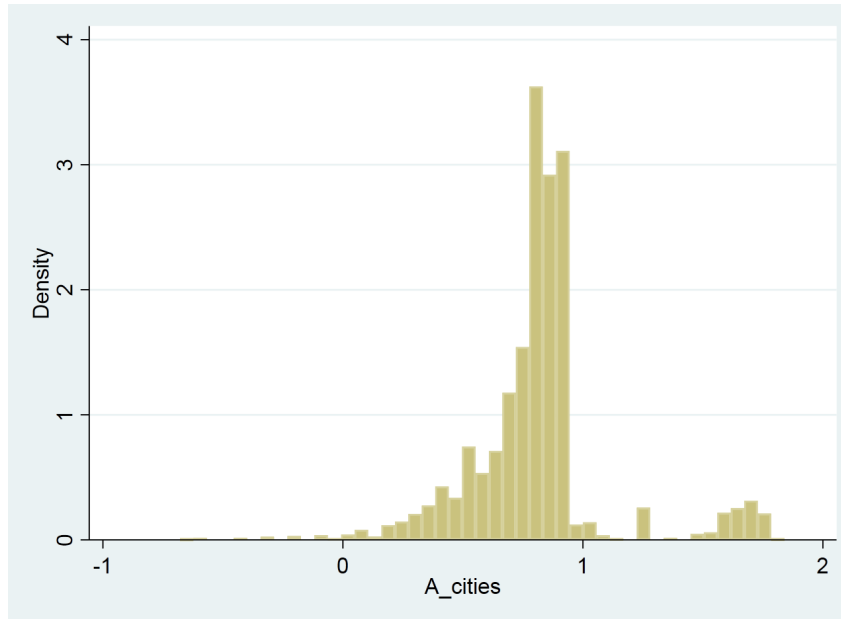
City-productivity distribution in 1998. This distribution was constructed by calculating the log average TFP of every firm in each city in China in 1998.

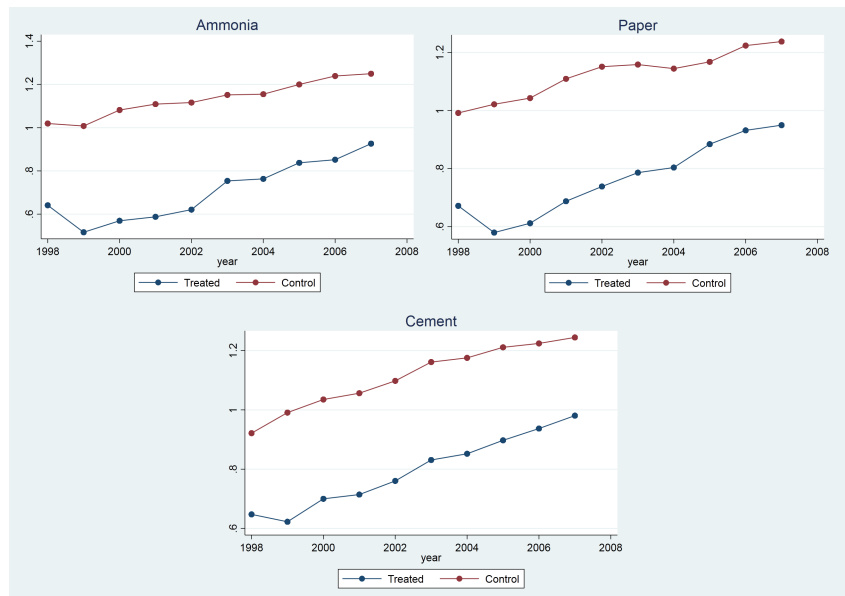## Figure 9: Standard Porter hypothesis: TFP trends
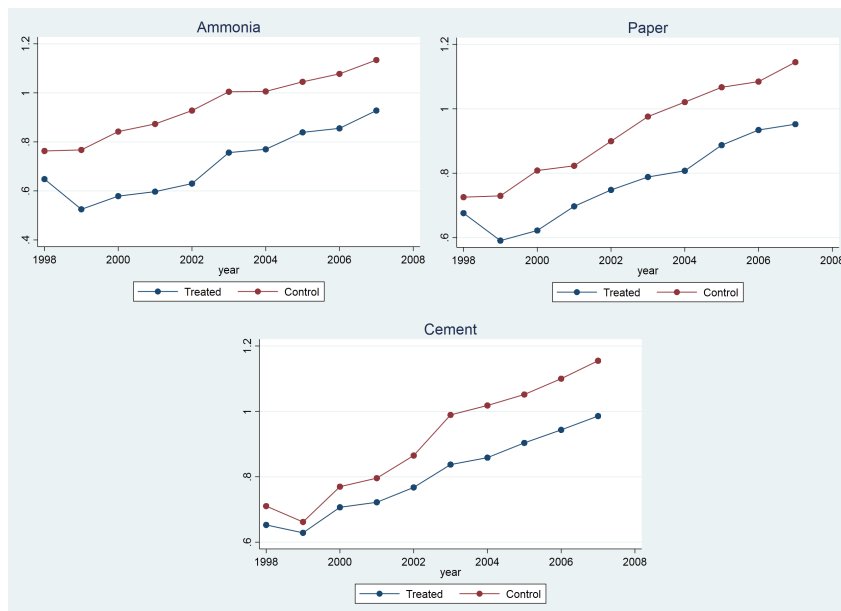
Log TFP trends for treated and control industries.

Figure 10: Spatial Porter Hypothesis: treated industries in different cities
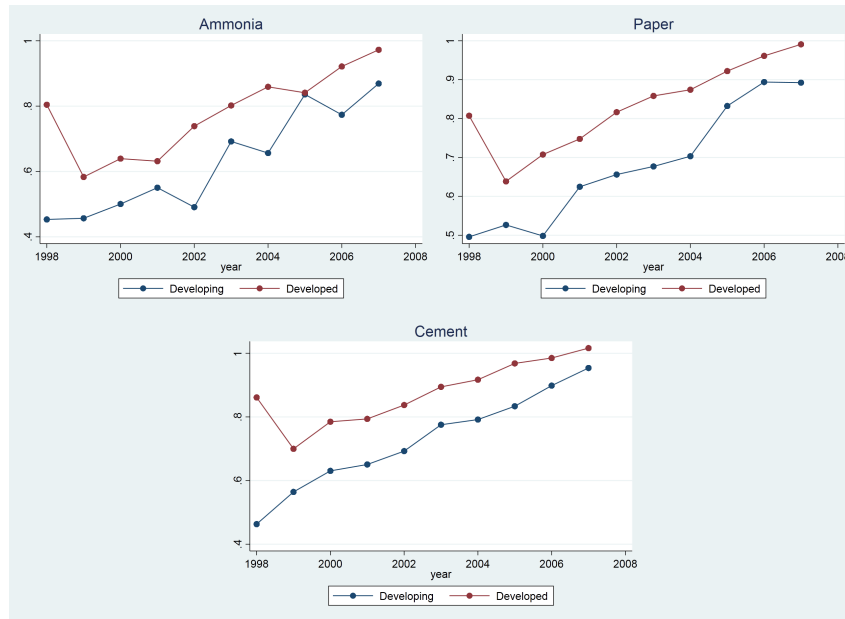
Log TFP trends pre treatment for treated and control industries.

Figure 11: Spatial Porter Hypothesis: treatment vs control groups

Log TFP trends pre treatment for treated and control industries.

Figure 12: List of Regulated Industries

Regulated industries:

Ammonia (Chemical materials and chemical products manufacturing (26)):

hylb:	Name:
2621	Nitrogen Manufacturing
2622	Phosphate fertilizer manufacturing
2623	Potash manufacturing
2624	Fertilizer manufacture
2625	Organic fertilizers and microbial fertilizer manufacture
2629	Other Fertilizer Manufacturing

Paper (Paper and paper products industry (22))

hylb:	Name:
2211	Bamboo wood manufacturing
2212	Non-wood bamboo manufacturing
2221	Paperboard manufacturing
2222	Handmade paper manufacturing
2223	Processing of paper manufacturing
2231	Paper and cardboard container manufacturing
2239	Other Paper Products Manufacturing

Cement (Non-metallic mineral products industry(30))

hylb:	Name:
3111	Cement Manufacturing
3112	Lime and gypsum manufacturing
3121	Cement Manufacturing

These are the industries that are regulated by the national pollution standards used in this paper. The first column of this picture, 'hylb', is the 4-digit industry classification. The number in parentheses after the official name of each industry is the 2-digit code.

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