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THE PORTER HYPOTHESIS GOES TO CHINA : SPATIAL DEVELOPMENT, ENVIRONMENTAL REGULATION AND PRODUCTIVITY

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

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Abstract

We examine the relationship between environmental regulation and competitiveness in China. Exploiting exogenous 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 newly 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 newly developing cities 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 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 development 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

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[1] Chinese Ministry of Environmental Protection.

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]. How can regulation of this quality induce technological change?

Exploiting exogenous 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 increased productivity of regulated firms that are located in newly 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. National Pollution standards have a positive effect on industry productivity in developing cities as compared to the same industries in other cities, for paper and cement industries. This means that environmental regulation probably changed the spatial distribution of technology in the country, more so than the direction of technology overall.

To interpret our results, we use the theoretical framework developed in Naso and Swanson (2017). In that paper, we develop a dynamic tax competition model where local governments compete for unskilled workers through variations in production taxes[3]. 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. In our model, 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 changes) are different across jurisdictions. The result is that, after environmental regulation is introduced, productive

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

[3] The model developed in Naso and Swanson (2017) builds on the tax competition literature, in the tradition of Zodrow and Mieszkowski (1986), Oates and Schwab (1988) and Bucovetsky (1991). We use elements of the more recent studies in this literature (Bucovetsky (2009) and Janeba and Osterloh (2013)) to develop a dynamic tax competition game with mobile workers and immobile physical capital.

factors move from more developed to developing jurisdictions, changing spatial economic development. Newly 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 environmental regulation, and particularly in regard to 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) find a negative impact of regulation on the TFP of manufacturing sectors in Quebec, Canada. Finally, two other studies that examine the Porter hypothesis for a set of countries find no evidence that it is valid. 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 econometric specification to test whether national pollution standards 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 environmental 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[4].

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

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[4] In this paper, we study the effect of three of these national pollution standards on industry productivity.

for all pollutants (Jiang et al. (2014)). The levy collected is to be used 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 can 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)). Hence local authorities decide how much levies to collect and when, leading to a process that diverges considerably from what is written in the law[5].

Two somewhat recent 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 di-

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[5] Evidence has also shown that some EPBs have been accused of corruption on using the levy system for their own benefit (Jiang et al. (2014)).

rect investment (FDI) and, using a DID approach, finds that there is a 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 regulation implementation[6]. Despite this, 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 a condensed version of the model developed in Naso and Swanson (2017)[7]. Our model describes the spatial evolution of production, workforce and productivity in an economy that operates within a federal regulatory structure. The economy consists of several development zones, each containing many local regulatory units. The level of technology is highest in the first zone initially, but, as development continues across time, the quality of technologies adopted generally increases.

The trade-off between cost of new capital and average national pollution will determine the spatial development pattern in this economy. The national government has to decide whether to finance new development zones—that is, to create new jurisdictions—comparing capital costs to costs of average pollution. As long as pollution reduction is greater than costs, the national government will keep diffusing production spatially. When this is not the case anymore, it will contain pollution by passing more stringent environmental regulation. The enactment of more stringent environmental regulation by the national government decreases local governments' tolerance towards pollution, and causes them to increase taxes.

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. Because jurisdictions differ in terms of their productivity values, 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.

So, the model demonstrates how development might shift spatially in response to environmental regulation. The movement of workers and

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[6] More generally, there is a literature that studies how environmental regulation affects comparative advantage of countries (see e.g. Broner et al. (2012)).

[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.

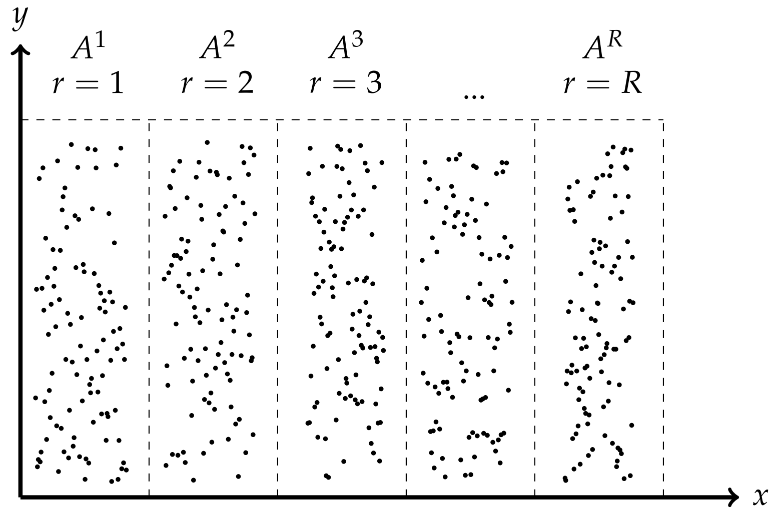
the development of new zones creates newly developing regions that release some of the pressure of pollution.

3.1 A Dynamic Tax Competition Model

Consider a national economy composed of many 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. 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.

Figure 1: Spatial Setup: Development Zones



Each dashed rectangle in this diagram represents a development zone (r) composed of N jurisdictions (black dots, i). A_i^r follows a normal distribution with average equal to A^r. $A^1 > A^2 > A^3 > ... > A^R$.

Figure 1 describes the spatial setup of this economy. Each dashed rectangle represents a potential development zone, r. These zones, located in the $\mathbb{R}^2$ space, are composed of N jurisdictions each, represented by the black dots. A jurisdiction can be identified by two coordinates, (i, r). The productivity of jurisdictions inside a zone follow a *normal* distribution with average A^r. We assume that average productivities are related in the following way: $A^1 > A^2 > A^3 > ... > A^R$. Jurisdictions located in zones that are closer to the origin, $(0, 0)$, are, on average, more productive than jurisdictions located in other zones.

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, $U(c_i^r)$, where c_i^r is consumption received in jurisdiction i. They have identical preferences and are mobile across jurisdictions, such that:

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

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. Moreover, they are obliged to use local productivity—i.e. the available vintage of capital—A_i^r.

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

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

where $0 < \alpha < 1$. Firms have to pay local production taxes, τ_i^r, to local governments.

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

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

When operating, firms emit pollution P_i^r, which will be assumed to remain within their jurisdiction:

$$P_i^r = \eta Y_i^r, \tag{4}$$

Pollution levels increase as a fraction of local output. The constant $0 < \eta < 1$ is the coefficient of emissions per output[8].

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[8] 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).

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

Local government's optimization problem is given by:

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

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 penalises excessive pollution and its health costs (e.g. via pollution levies).

The difference between local pollution levels and the national pollution threshold can be generally interpreted as the level of local tolerance towards pollution levels, relative to the regulatory norm.

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. This amount is assumed to be proportional to the local population and to the national pollution threshold, $\bar{P}$, established by the national government:

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

The constant $0 < \phi < 1$ converts pollution units into health cost units[9]. The national government's optimization problem can be described by,

$$\underset{a=\{1,0\}}{\text{minimize}} \quad P^{av}(a, R) + a \cdot c \cdot A^{R+1} \tag{7}$$

where a refers to the government's possible actions: to finance a new zone, $a = 1$, or not, $a = 0$; $c \cdot A^{R+1}$ is the cost of financing a new development zone and $P^{av}(a, R)$ describes the average local pollution in this economy. R refers to the total number of zones.

This expression describes a cost minimization problem: i) the cost of pollution and ii) the cost of spatial economic development. Average pollution is a decreasing function of a: with more development zones, production will diffuse nationally and average pollution will decrease.

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

The cost of financing new capital, however, is positive and proportional to the average vintage of capital that will be financed.

Hence, the national government will choose to finance a new development zone as long as,

$$|\Delta P^{av}(a, R)| > c \cdot A^{R+1} \tag{8}$$

that is, reduction in average pollution is greater that the cost of new jurisdictions. If the national government chooses not to finance a new zone, $a = 0$, then the national threshold, $\bar{P}$, is adjusted to be equal to the current average pollution in the country[10]:

$$\bar{P} = P^{av}(R) \tag{9}$$

3.1.2 The Game

Suppose that, initially, there is only one development zone in this economy. Repeatedly, the national government has to decide whether to finance the creation of new capital, that is, new jurisdictions. As described in figure 1, these jurisdictions will form a new development zone, characterized by a productivity distribution (with average A^r). The cost of financing a new zone is proportional to A^r, so that more productive capital is more expensive than less productive one.

Workers can migrate within and across zones—such that wages are equalized nationally every time local governments set production taxes. The game ends when the national government decides not to finance a new development zone, and $\bar{P}$ is adjusted.

Our game is described in figure 2. The national government moves first. If it decides to finance a new zone, then local governments in that zone set production taxes together with local governments in the first zone. After taxes are set, workers migrate to equalize utilities and wages across the economy. This is repeated until the national government chooses not to finance a new development zone. Then $\bar{P}$ is adjusted and wages are equalized for the last time.

3.1.3 Results

In this section we present the results of a simulation of the game described previously (Naso and Swanson (2017))[11]. No attempt has been made to calibrate our model. We are only interested in illustrating its

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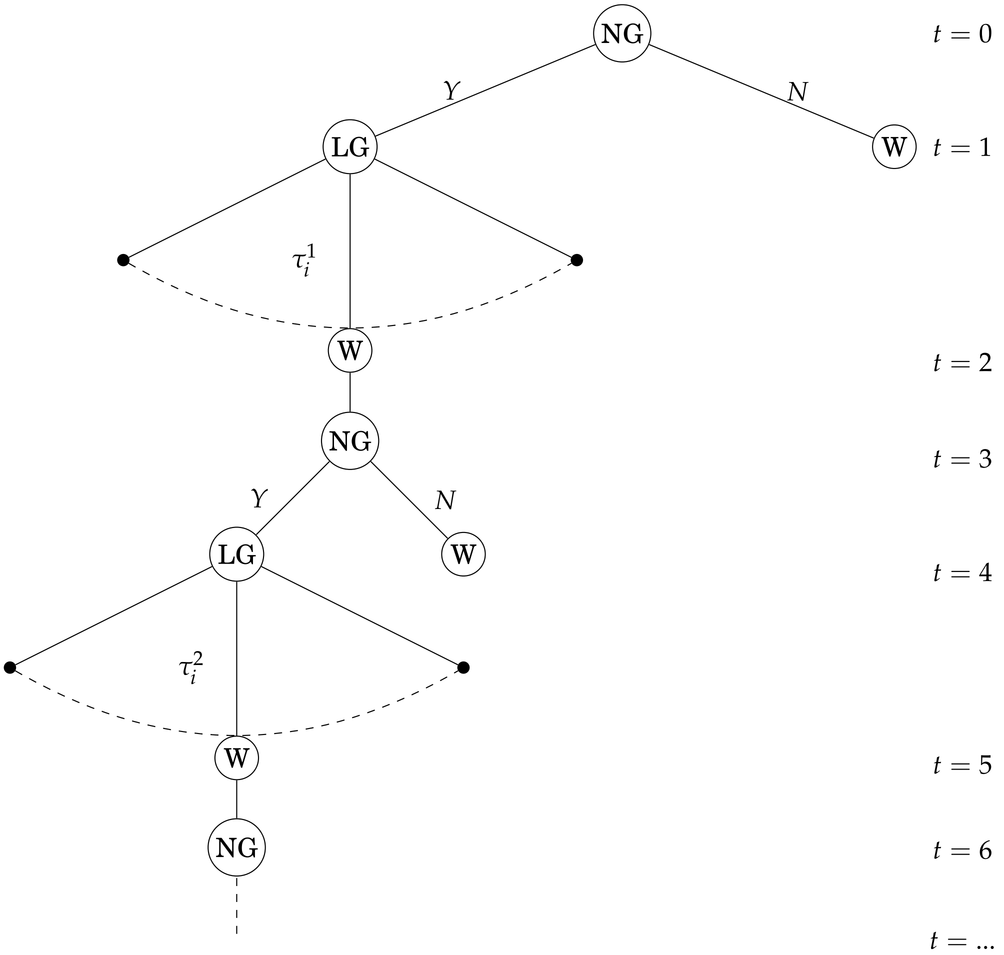
[10] The idea here is to capture in a simplified way the trade-off the national government might face between promoting spatial economic growth and decreasing national pollution. By financing new capital, the national government increases national output and allows investments to reach once undeveloped regions. However, at the same time, this increases pollution and health costs in these areas.

[11] We present parameter values of this simulation in the Appendix.

qualitative dynamics. The parameters used in the simulation are given in the Appendix. Average productivity in each development zone follows $A^r = A^1 \cdot 0.8^{r-1}$, where A^1 is the average productivity in the first zone.

Figure 2: Game Tree



NG: National Government decides whether it creates a new zone, $a \in \{Y, N\}$. If $a = N$, $\bar{P}$ is adjusted.
LG: All local governments set production taxes—or update them, $\tau_i^r \in [0, 1)$.
W: Workers migrate and wages are equalized across the economy, $w_i^r = w_j^r, \forall i, j, r$.

For the parameter values used in our simulation, the game ends with four development zones, right after the national government chooses not to finance the fifth one. Figure 3 shows the national government's decision problem. Note that the two curves depicted in the figure intersect before $R = 5$. This means that the cost of financing the fifth zone is greater than reduction of average pollution.

After the national government decides not to finance a new development zone, a new national threshold, $\bar{P}$, is set. There is a reduction in the threshold, forcing local governments to increase local taxes—this happens because they have fewer resources to deal with health costs. Figure 4 compares two situations: i) in blue, we present average optimal taxes, local population and local output for each zone before $\bar{P}$ changes; ii) in red, we present these variable again, but for the new value of $\bar{P}$.

We see that optimal taxes increase in all four development zones after the threshold is adjusted. However, this increase is not homogeneous. Zones that have greater average productivity increase taxes more—relatively to their initial value—than other zones. This has an impact in local population and local output.

As figure 4 shows, workers leave the most productive zone and migrate to newer zones. This happens because an increase in taxes is converted into a decrease in wages. Workers move, then, to equalize wages nationally. This movement of workers changes the national distribution of output. Newer zones receive workers and this increases their average output. The result is that more stringent environmental regulation shifts production from the most to the least developed zones.

Therefore, the relationship between environmental regulation and pollution has two effects on productivity. First, for a given initial national threshold, the trade-off between pollution reduction and cost of new capital will determine whether once undeveloped regions will become developed. The financing of new zones brings capital to inland regions of this economy, and increases productivity in these regions. Second, when the national threshold changes, and production shifts to the least developed zones, jurisdictions in these zones experience an increase in effective productivity—as compared to the initial situation[12].

3.2 Discussion

The results of our model demonstrate two things. First, the creation of new zones is partly determined by the outcome of the tax competition game—that, in turn, is determined by the *ex-ante* national distribution of productivity. The reduction in average local pollution brought by the creation of a new zone is a function of the way workers are distributed spatially. Second, workers and production shift from more to less productive regions when more stringent environmental regulation is introduced. A more stringent regulation changes the outcome of the tax competition game. The increase in taxes in undeveloped jurisdictions is smaller than in developed ones. Workers then migrate to these zones, and production shifts to this region of the country.

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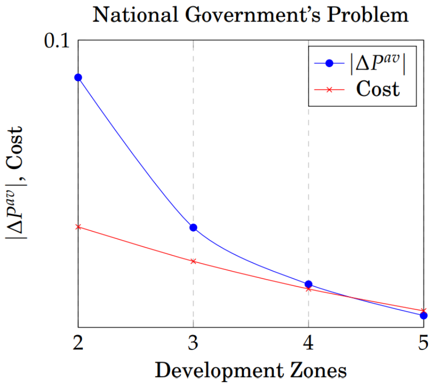
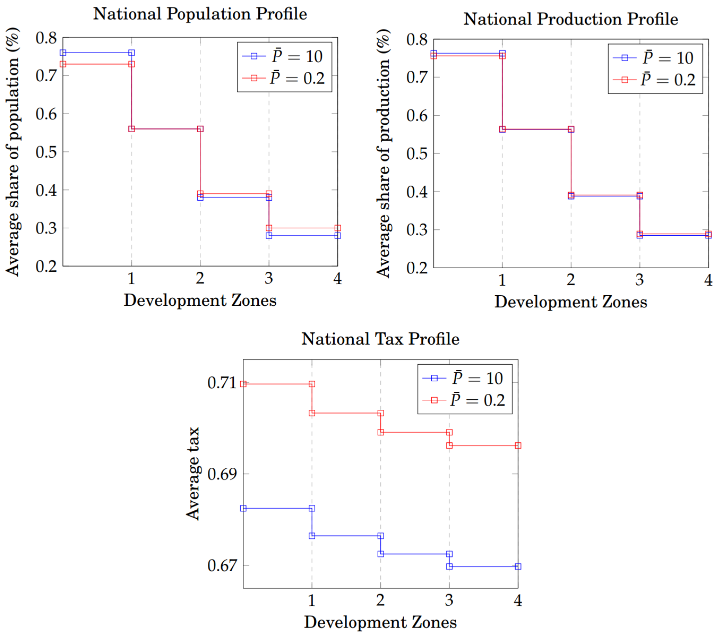
[12] A way to see that is to compare local output in a jurisdiction in the newest development zone before and after the new threshold is set. Initial local output is given by $Y^r_{0,i} = A^r_{0,i}(L^r_{0,i})^\alpha$. After the new threshold, $Y^r_{1,i} = A^r_{0,i}(L^r_{0,i} \cdot b)^\alpha$, where $b > 1$. We have that $Y^r_{1,i} = A^r_{0,i} \cdot b^\alpha (L^r_{0,i})^\alpha = A^r_{1,i}(L^r_{0,i})^\alpha$. And, because $b^\alpha > 1$, we have that $A^r_{1,i} > A^r_{0,i}$.

Figure 3: Simulation: Development Zones



Initially, there is one development zone. As the game continues, new jurisdictions are created and four development zones are established. The game ends after the national government decides not to finance the fifth zone. The graph depicts the national government's decision problem. The blue curve is the reduction in average pollution as a function of the number of development zones. The red curve is the cost of financing a new development zone. When $|\Delta P^{av}| < Cost$, the national government stops financing new zones.

Figure 4: Population and Production Profiles



These three graphs show the national profile of population, production and taxes for each development zone. We show the average jurisdiction share in each zone of total population and production before and after $\bar{P}$ is adjusted; and the average tax local governments set in each zone. Jurisdictions in zones 3 and 4 experience an increase in output and population shares.

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

4 Data and Descriptive Statistics

National Pollution Standards: The piece of environmental regulation we use in our analysis is the national pollution standards (NPS). The enactment of new NPS 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[13].

Table 1 details the specific NPS we use. In the second column, 'Doc Title', we see the groups of industries these standards are regulating. These are ammonia, paper and cement industries. Note that these are broad industries that encompass several subindustries. We present a full list of regulated industries—according to the 4-digit classification—in the Appendix[14]. We call these *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.

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[13] Chinese Ministry of Environmental Protection (MEP).

[14] 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.

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 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 focus 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[15]. Summary statistics for the main characteristics of the firms are presented in table 2.

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[15] 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,

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. We have to be careful in extending the validity of our results to the whole population of Chinese firms, though.

To perform our empirical analysis, we construct a panel of industries in cities[16]. 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[17]. 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)[18]. 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)[19].

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 hypothesis. 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 ammonia and cement, and a negative effect for the paper industry. Second, we present our results for the spatial Porter hypothesis. We show that environmental regulation increased productivity of regulated industries in developing cities. We finish this section by pointing out possible mechanisms for this increase.

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small firms with poor documentation would have been included, leading to increased noise in our sample.

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

[17] This distribution is plotted in the Appendix (figure 5).

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

[19] Average TFP growth in the last decade 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)).

Table 2: Descriptive Statistics for Surviving and Non-surviving firms

Year	Pollution Int.			TFP		Employees		Ownership		
		Surv.	Exit	Surv.	Exit	Surv.	Exit		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.

5.1 Identification Strategy

We employ 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 Common trends in productivity prior to NPS enactment;

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 pre-treatment trends of TFP per worker for control and treatment groups. When we use *control* groups, we construct these such that absolute differences in TFP pre-treatment between control and treatment groups are minimized.

Exogeneity of NPS is not testable, but two suggestive arguments appear to show that the second assumption also holds. First, examining the way national environmental regulation in China is drafted and approved, it seems highly 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 NPS.

Second, a simple 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 Table 3). This suggests that the central government is not looking specifically at the productivity of industries when enacting NPS.

5.2 Testable Hypothesis

We test two empirical hypotheses in this paper.

H1 NPS enactment increases average industry productivity in 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—or a negative—effect on average industry TFP.

H2 NPS enactment increases average industry productivity in regulated industries in developing cities.

We call this the spatial Porter hypothesis. National environmental regulation has the effect of reallocating productivity spatially in China. Given that allocation to developing regions occurs at later points in time, these regions benefit from newer vintages of technology. 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.

Table 3: 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.
$^{*}\ p < 0.10$, $^{**}\ p < 0.05$, $^{***}\ p < 0.01$.

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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**. Our baseline specification is

$$log(TFP_{it}) = \gamma_i + \lambda_t + \delta_i \cdot (reg_i \cdot post_t) + X'_{it}\theta + \epsilon_{it}, \tag{10}$$

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

X_{it} is a vector of five controls: log of physical capital per worker, k_{it}, log of age of average firm, age_{it} , log of current assets per worker, $assets_{it}$, proportion of state owned firms in a industry, soe_{it}, and proportion of firms located in a special economic zone, sez_{it}[20].

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 enactment of NPS on average industry productivity of treated industries. For **H1** to be true, we need δ_i to be positive and statistically significant.

We run one regression for each treated industry. We construct control groups in the following way. We calculate squared differences of log TFP 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 10th percentile of this distribution[21].

Table 4 presents our results. Ammonia and cement have statistically insignificant coefficients. This means that national pollution standards do not have any effect on these two industry productivities. We have a negative coefficient for the paper industry. The enactment of standards for this industry decreases TFP in approximately 29%[22]. Thus, environ-

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[20] Our control variables remain the same for all regressions we run. We use *per worker* variables to control for average firm size.

[21] Figure 6 in the Appendix shows TFP trends for treated and control groups for each industry. Note that trends for ammonia and cement are parallel, while treated and control groups for paper do not present such a clear parallelism. We repeat the regressions for paper that are shown in table 5 with a control group below the 5th percentile (this increases parallelism, but decreases the number of observations in our regressions). Results are similar.

[22] We run a placebo regression with an arbitrary treatment date ($year = 2000$) for the paper industry. We obtain statically insignificant results, suggesting that our results in table 4 are not driven by some unobserved variable.

mental regulation is detrimental to industry productivity.

Therefore, we have that **H1**—the standard Porter hypothesis—does not hold for these industries and this set of environmental regulation in China[23].

5.4 Spatial Porter Hypothesis

We now test **H2**. We show here that this hypothesis holds for some groups of developing cities.

Developing cities are here defined as cities that have an average log TFP per worker below the 25th percentile of the 1998 city-productivity distribution. We begin by using the following triple DID specification[24],

$$\begin{aligned} log(TFP_{ict}) = \gamma_{ic} + \lambda_{tc} + \mu_{it} + \delta_a \cdot (ammonia_i \cdot post_t \cdot \underline{TFP}_c^{25th,1998}) + \\ \delta_p \cdot (paper_i \cdot post_t \cdot \underline{TFP}_c^{25th,1998}) + \\ \delta_c \cdot (cement_i \cdot post_t \cdot \underline{TFP}_c^{25th,1998}) + \\ X'_{ict}\theta + \epsilon_{ict}, \end{aligned} \tag{11}$$

where TFP_{ict} is average TFP per worker of industry i in city c at year t; $ammonia_i$, $paper_i$ and $cement_i$ are dummies for our treated industries; and $post_t$ is a dummy for year of treatment. X_{ict} is a vector of five controls[25]. We include three levels of fixed effects: year, city and industry (γ_{ic}, λ_{tc} and μ_{it})[26]. Standard errors are clustered by city and industry. 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.

In table 5, we see that there is an increase in productivity of regulated industries in developing cities when compared to all other industries. Productivity of cement increases by approximately 15%, whereas ammonia and paper have an increase of approximately 13% and 9%, respectively.

This initial set of results suggests that NPS produced a reallocation of productivity in space. Productivity of regulated industries that

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[23] It is possible to verify empirically, for the three industries analyzed here, a vintage capital effect, that is, that the ratio between TFP growth and physical capital growth has been increasing over time. This suggests that, even though regulation does not influence TFP, the vintage of capital matters.

[24] This is similar to the difference-in-difference-in-differences (DDD) specification. This strategy is employed in Shi and Xu (2017), where authors also exploit three levels of variation: time, location (province) and industry (pollution intensity).

[25] The controls are: log of physical capital per worker, k_{ict}, log of age of average firm, age_{ict}, log of current assets per worker, $assets_{ict}$, proportion of state owned firms, soe_{ict}, and proportion of firms located in a special economic zone, sez_{ict}.

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

are located in developing cities—usually located in inland provinces in China—increased. However, the coefficients we just presented might not be capturing an increase in productivity due to regulation, but due to unobserved variables we could not control for.

Table 4: DID of NPS on TFP of treated industries

Variable	**(1)**	**(2)**
Ammonia		
δ_a	0.073	0.005
	(0.107)	(0.131)
Controls	No	Yes
Year FE	Yes	Yes
Ind FE	Yes	Yes
Obs	450	448
R^2	0.77	0.81
Paper		
δ_p	-0.184	-0.289***
	(0.109)	(0.061)
Controls	No	Yes
Year FE	Yes	Yes
Ind FE	Yes	Yes
Obs	420	418
R^2	0.73	0.81
Cement		
δ_c	0.024	0.005
	(0.045)	(0.053)
Controls	No	Yes
Year FE	Yes	Yes
Ind FE	Yes	Yes
Obs	285	285
R^2	0.89	0.91

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

Productivity of Chinese firms has been increasing in the last years, and it seems natural that industries in poorer places benefited more from this increase comparatively to other industries. To make sure that this is not the case, we run a placebo regression, selecting an arbitrary year of treatment (results are given in the Appendix). As we can see in the Appendix, coefficients for paper and cement are robust to this check, whereas coefficient for ammonia does not pass the test. Thus, it is possible that the productivity of the ammonia industry in developing cities is increasing because of unobserved variables, such as subsides from the government or foreign investment[27].

We investigate further the effect of regulation on productivity in developing cities by analyzing productivity increases in each segment of our city-productivity distribution. To do that, we construct control groups by matching industries that have similar log TFP per worker trends before treatment dates[28].

We then run three distinct regressions—one for each industry—with three interaction terms in each: $ind_i \cdot post_t \cdot \underline{TFP}_c^{10th,1998}$, $ind_i \cdot post_t \cdot \underline{TFP}_c^{25th,1998}$ 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 between the 25th percentile and the median.

We present our results in figure 5[29]. Dashed lines in each graph are 95% confidence intervals. We see that the effect of environmental regulation in TFP per worker is decreasing with distribution percentile. For paper, for example, there is an increase of roughly 26% in regulated industries in cities at the bottom 10% of the distribution if compared to similar industries in other cities. This effect is reduced to zero for the group of industries located in cities in between the 25th percentile and the median of the distribution. The greatest observed increase is for the bottom 10th of ammonia.

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[27] As previously mentioned, because ammonia is used in fertilizers, the central government sees it as strategic for food security reasons (Zhou et al. (2010)). This industry could be receiving governmental subsidies, something we cannot capture in our regressions.

[28] This is similar to what we did in the previous section. We calculate squared differences of log TFP per worker between regulated industries in cities that are below the median, $\underline{TFP}_c^{50th,1998}$, and 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. Figure 7 in the Appendix shows log TFP per worker trends for treated and control groups for each industry. In general, these two groups have fairly parallel trends before regulation, with the exception of cement. Note that our control groups are composed of industries that are not regulated and are located in non-developing cities. The assumption here is that if environmental regulation was not enacted, log TFP per worker of our treated group would behaves similarly to the one of the control group.

[29] We assume that the coefficient between percentiles is constant.

Table 5: NPS on TFP of regulated firms in developing cities

Variable	Coefficient
δ_a	0.133***
	(0.028)
δ_p	0.090***
	(0.015)
δ_c	0.148***
	(0.020)
k_{ict}	0.005**
	(0.003)
soe_{ct}	-0.018***
	(0.005)
sez_{ct}	-0.001
	(0.009)
$ages_{ict}$	-0.004
	(0.002)
$assets_{ict}$	0.007**
	(0.004)
Obs	146,901
R^2	0.66

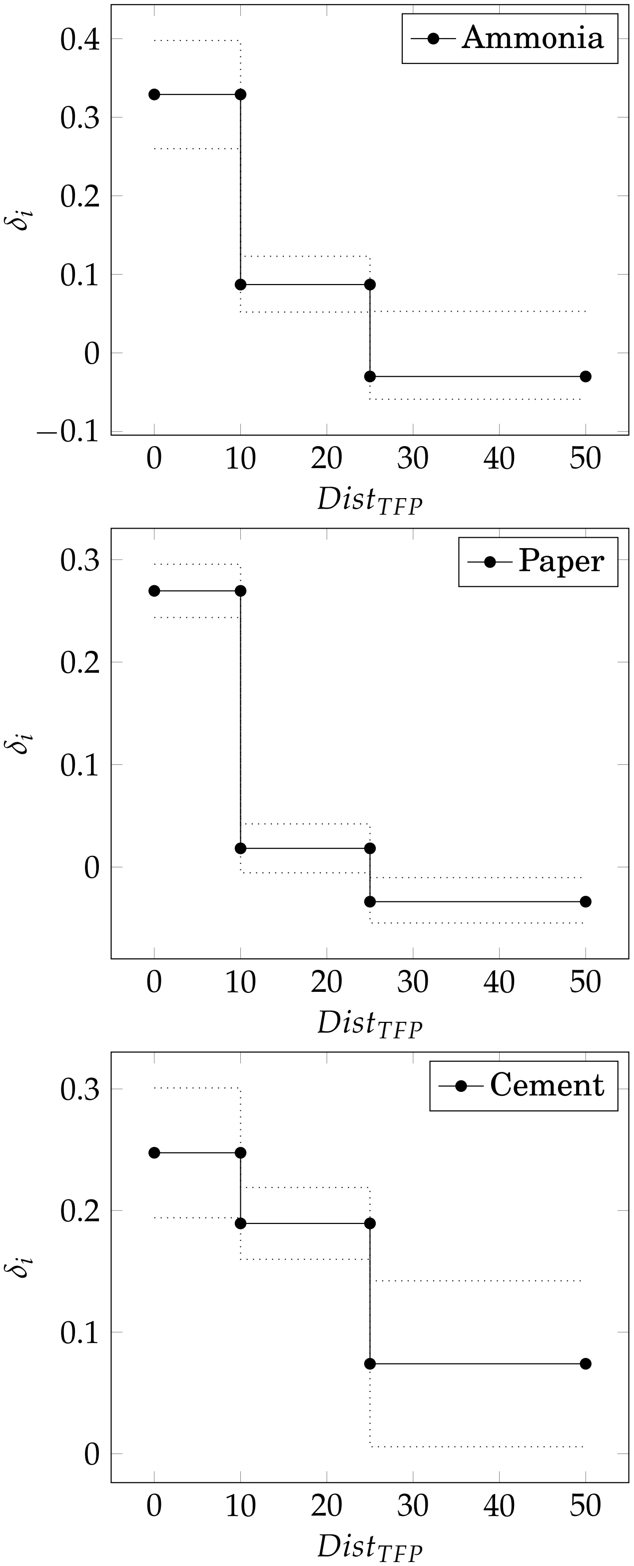
Our dependent variable is log TFP per worker of an industry in a city at a year. Standard errors are clustered by city and industry.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

These results show that cities in the bottom of the city-productivity distribution—the least developed ones—experienced the greatest increase in productivity after NPS are effective. They suggest that environmental regulation triggered a movement of productive input factors from the most to least developed cities in China. Relatively to their size, cities in the bottom of the distribution benefited the most from this movement.

Therefore, we can conclude that regulated industries in developing cities experienced an increase in productivity compared to similar industries in other cities. This increase seems to be caused by environmental regulation. This is evidence that **H2** holds, that is, that the spatial Porter hypothesis is valid. However, because we are comparing different industries in different cities, there might still be some time varying effects related to city-industry characteristics that we are not able to capture in our analysis.

The next step is to fix the industry dimension and to compare only regulated industries located in different cities. In China, industries are classified according to what they produce. Although firms situated in more developed cities are able to access better infrastructure and tech-

Figure 5: NPS on TFP: different percentiles



We present the coefficient for different percentiles of the city-productivity distribution in 1998. Dashed lines are 95% confidence intervals. We assume that coefficients are constant between percentiles. Standard errors are clustered by city and industry.

nology, we believe that, because they produce the same output, productivity of industries with the same classification in different cities will evolve fairly similarly[30].

Figure 6 shows average city TFP for the three industries studied here. To construct this picture, we aggregated TFP averages *pre* and *post* treatment for each city. Darker colours mean higher TFP. The picture illustrates the spatial impact of NPS.

We see that, after environmental regulation, productivity of paper and cement industries in inland cities increased compared to coastal cities. There are more darker spots in the interior of the country after regulation was enacted for these two industries. Ammonia does not present such a clear trend. It seems that productivity differences remained almost constant after regulation.

Thus, according to figure 6, it seems that environmental regulation changed the spatial distribution of productivity of paper and cement industries in China. We test now whether this is just a spatial correlation.

To do that, we run three regressions with the following specification form:

$$\begin{aligned} log(TFP_{ict}) = \gamma_{ic} + \lambda_{tc} + \mu_{it} + \delta_{i,25th} \cdot (post_t \cdot \underline{TFP}_c^{25th,1998}) \\ + X'_{ict}\theta + \epsilon_{ict}, \end{aligned} \tag{12}$$

where TFP_{ict} is average TFP per worker of industry i in city c at year t. X_{ict} is a vector of five controls[31]. Again, we include three levels of fixed effects: year, city and industry (γ_{ic}, λ_{tc} and μ_{it}). Standard errors are clustered by city[32].

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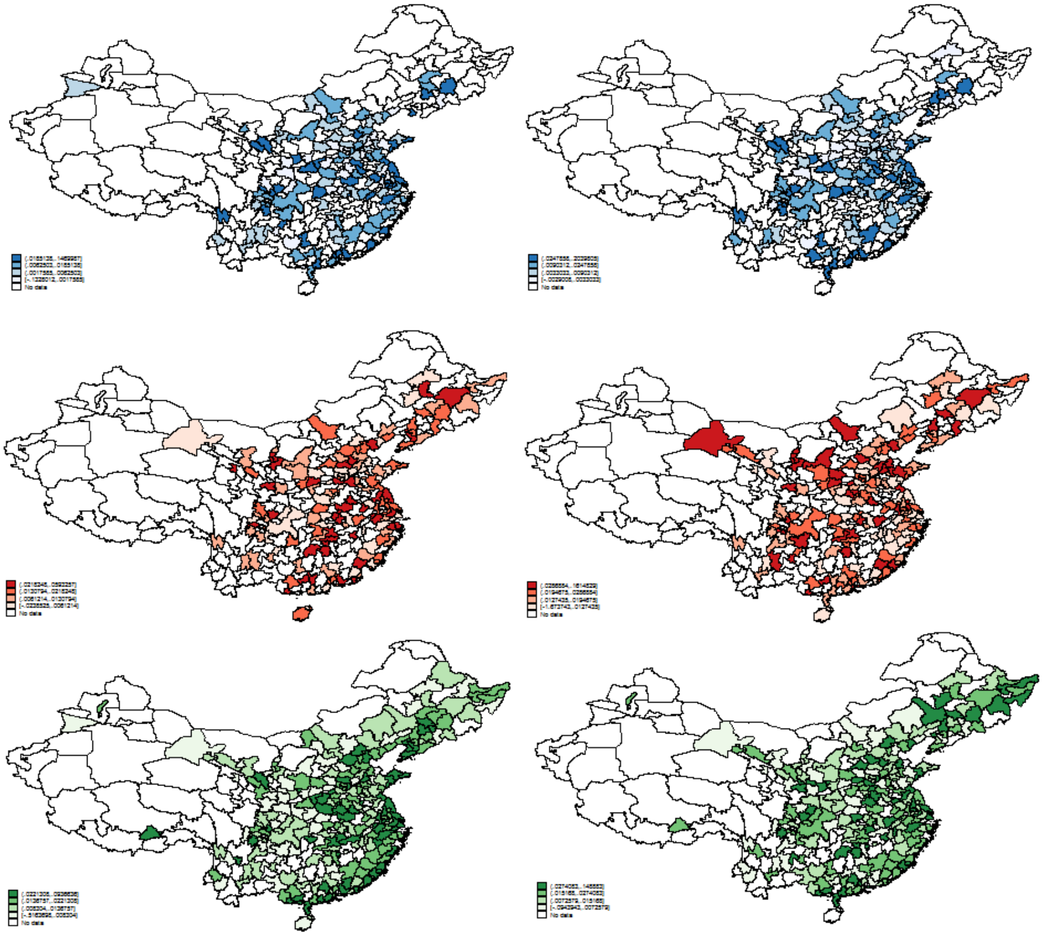
[30] Figure 8 in the Appendix plots log TFP per worker for regulated industries in different cities, developing vs non-developing. Trends are fairly parallel pre-treatment.

[31] The controls are: log of physical capital per worker in an industry, k_{ict}, log age of average firm in an industry, age_{ict}, log of current assets per worker, $assets_{ict}$, proportion of state owned firms in the city, soe_{ict}, and proportion of firms located in a special economic zone in a city, sez_{ict}.

[32] We follow the usual rule of thumb of clustering for at least 50 clusters (to ensure that the required asymptotic results apply).

Figure 6: Average city-TFP before and after NPS



We present average city-TFP for the industries studied before and after standards were turned effective. Ammonia is depicted in blue, paper in red and cement in green. On the left hand-side, we have city TFP before environmental regulation, and on the right hand-side after it. Darker colors represent greater productivity.

Table 6 presents our results. They suggest that there was an increase in productivity of regulated industries located in cities at the bottom of the productivity distribution after NPS were effective. For ammonia, the increase on industries at the bottom 25th was approximately 22%. The increase in productivity for the same group of the paper industry was roughly equal to 11%, and for cement equal to 13%.

Table 6: NPS on Regulated Industries in Different Cities

Variable	**Coefficient**	**(Std. Err.)**
$\delta_{a,25th}$	0.219***	(0.039)
k_{ict}	0.006	(0.013)
soe_{ct}	0.052**	(0.015)
sez_{ct}	-0.018	(0.039)
$ages_{ict}$	0.003	(0.019)
$assets_{ict}$	0.016	(0.014)
Obs	2,329	
R^2	0.72	
$\delta_{p,25th}$	0.105***	(0.035)
k_{ict}	0.024***	(0.087)
soe_{ct}	-0.017	(0.037)
sez_{ct}	0.027	(0.048)
$ages_{ict}$	-0.049	(0.030)
$assets_{ict}$	0.006	(0.012)
Obs	2,806	
R^2	0.61	
$\delta_{c,25th}$	0.131***	(0.045)
k_{ict}	0.019*	(0.011)
soe_{ct}	-0.045*	(0.025)
sez_{ct}	-0.021	(0.067)
$ages_{ict}$	-0.007	(0.014)
$assets_{ict}$	0.016	(0.019)
Obs	3,581	
R^2	0.70	

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

This difference in magnitude might be explained by the nature of the ammonia industry. Compared to cement and paper, ammonia production requires lighter equipment and pollutes less, on average. It is then easier for firms that produce ammonia to move across regions and to increase their capacity after new environmental regulation is effective. The same can be said about productivity. The costs related to rearranging the production processes and, eventually, increasing productivity are lower than for the other industries.

Again, we test our results with placebo regressions for an arbitrary period of treatment (see table 7 in the Appendix). We conclude that estimates for paper and cement are robust to this check, but, once more, ammonia doesn't pass the test[33].

Overall, our main results appear to confirm that the enactment of environmental regulation increased average productivity of regulated firms in developing cities, at least for the case of paper and cement. This is evidence in favor of our second testable hypothesis, the spatial Porter hypothesis. Regulation triggered a process of technological reallocation across the country.

5.5 Auxiliary Results

Technological reallocation might be followed by shifts in input factors and production. Changes in these variables might help explain the mechanisms behind changes in productivity. In this section, we briefly describe what happens to workforce and output before and after environmental regulation.

Figure 7 shows what happens to the size of the workforce of regulated industries in the bottom and top 25th of the city-productivity distribution. The bottom 25th of ammonia sees a slight increase in workforce size, whereas the top 25th experiences a reduction in the total number of employees. Workforce in the bottom 25th of the cement industry remains constant after NPS turned effective, while the top 25th sees a substantial decrease in it. Finally, the greatest increase in workforce size after regulation happens for the bottom 25th of paper.

This figure suggests that, at least for the case of paper and cement, environmental regulation generates migration of workers in the top and bottom of the distribution of cities. To further investigate this, we run a DID regression similar to the one in the last section to test whether workforce variation was caused by regulation enactment[34]. As table 8 in the Appendix shows, variation in the size of the workforce is only statistically significant for paper—a 39% increase in workforce after NPS were effective as compared to the rest of the distribution.

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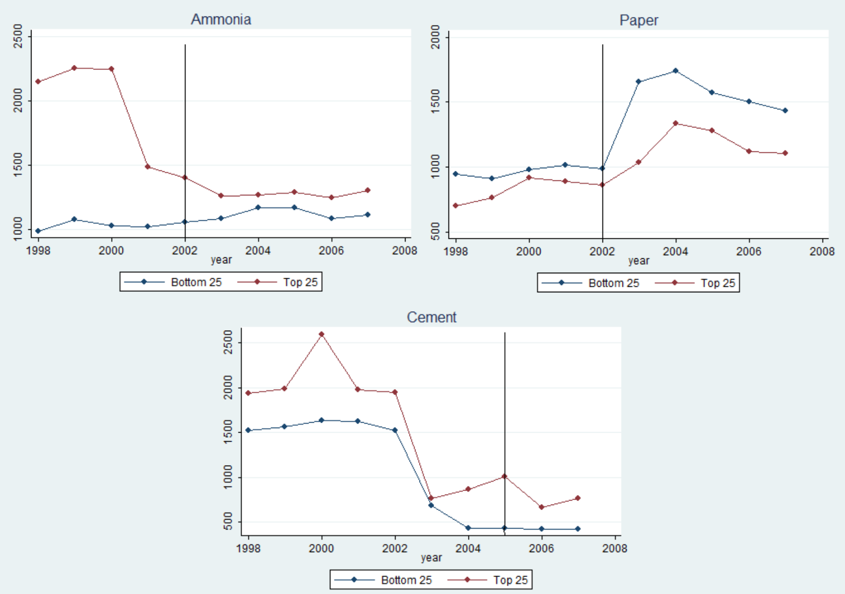
[33] Following Bertrand et al. (2004), we test for possible serial correlation. To do that, we aggregate data pre and post regulation, such that we only have two points. We then run a DID regression with the same controls and fixed effects we used before. Our results show that estimates for ammonia and paper pass the test, but not estimates for cement.

[34] We only include three controls now: age of average firm in an industry, a_{ict}, proportion of state owned firms in the city, soe_{ct}, and proportion of firms located in a special economic zone in a city, sez_{ct}. Standard errors are clustered by city. The dependant variable is average log number of employed workers in an industry in a city.

Figure 7: Workforce variation



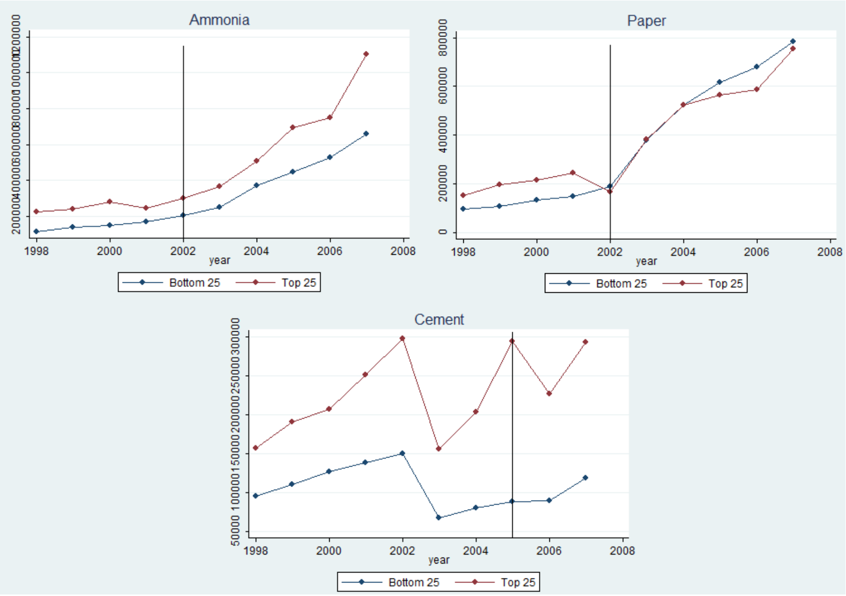
This figure depicts what happened to the total workforce in the bottom and top percentiles of the city-productivity distribution for our treated industries before and after regulation. There was a substantial increase in workforce in the bottom 25th of the paper industry.

Figure 8 shows total output of an industry in a city for the bottom and top 25th of the city-productivity distribution. Trends for the bottom and top 25th of ammonia are similar. There is no evidence that NPS generates any difference in output trends between these two groups. The same can be said for the paper industry. Trends for bottom and top 25th of the city-productivity distribution are almost identical. It seems that the increase in workforce we observe in figure 7 was not converted into increased production.

Finally, the top 25th percentile of the city-productivity distribution for cement experiences a considerable decrease in output after environmental regulation. This is accompanied by a small increase in output at the bottom 25th.

Hence, figure 8 shows that regulation could only have shifted production from the top to the bottom 25th for the cement industry. Once more, we run DID regressions to check whether this visual correlation might be causal. However, all our coefficients of interest are statistically insignificant.

Figure 8: Output variation



This figure depicts what happened to the total output in the bottom and top percentiles of the city-productivity distribution for our treated industries before and after regulation.

These results suggest two things. First, spatial changes in productivity did not convert into changes in production. One reason for that is that, since spatial differences in productivity are high in China and output is proportional to TFP, productivity increases in inland cities were not enough to increase output. Second, at least for the paper industry, workforce movement is probably related to productivity changes. It seems that NPS not only caused an increase in productivity in developing cities, but also made workers migrate to these cities.

6 Discussion and Conclusion

Environmental regulation and economic development seem to have been moving in tandem in China. Productivity growth and enactment of environmental regulations have both been increasing since the 1970s. 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 exactly the case.

For the industries analyzed here, the strong version of the Porter hypothesis does not hold. Environmental regulation has a zero or negative effect on industry productivity. On the other hand, national pollution standards affect spatial distribution of technology. Paper and cement firms located in developing cities have their productivity increased after regulation is enacted. This is evidence that the spatial Porter hypothesis hold; environmental regulation shapes spatial patterns of economic development 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 (Naso and Swanson (2017)). The national government seeks to promote economic development financing the construction of new development zones in inland regions. Its objective is to diffuse production spatially to keep average national pollution at low levels. Every time a new zone is created, there is creation of capital—and an increase in productivity—in once undeveloped regions.

Local governments in all jurisdictions repeatedly 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 stops financing new zones and sets a more stringent national environmental regulation, local governments increase taxes. However, taxes increase at different rates, depending on 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.

Due to limitations in our data, we are not able to examine in detail the mechanisms of our model. We show that, for the paper industry, there are signs of workers' migration to developing cities after the enactment of NPS. This migration, however, was not accompanied by proportional increases in output. Our auxiliary results also show that cement industry in developed cities experienced decreases in workforce and output after regulation, but these variations are not statistically significant.

7 Appendix

7.1 Simulation: parameter values

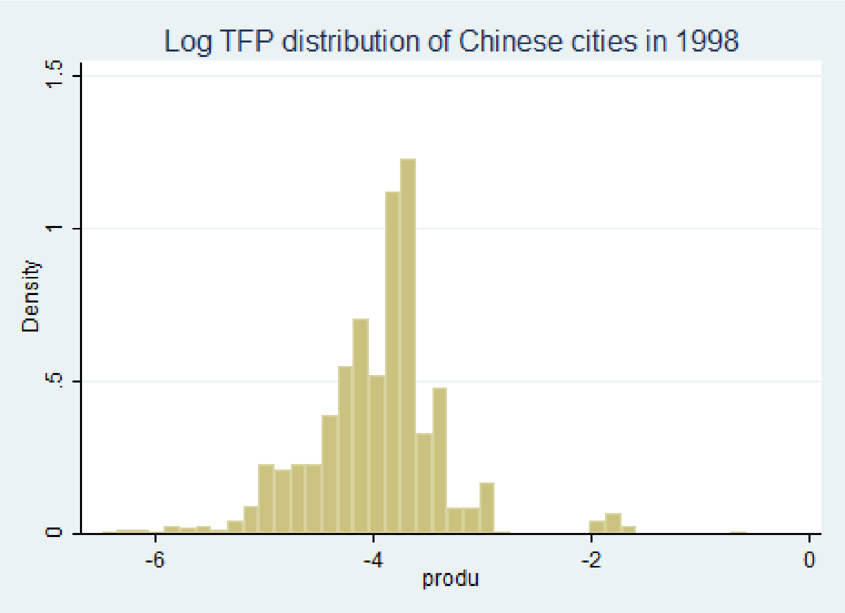
The following table specifies the parameter values used for the simulation.

Table 7: Parameter values for the Simulation

Parameter	Value	Description
N	50	Number of jurisdictions in each Development Zone
$\bar{L}$	1	Total Population
Production Parameters		
A^1	$\mathcal{N}(6,1)$	Productivity of the first Zone
α	0.3	Labour elasticity
Environmental Parameters		
η	0.2	Emissions per output (intensity)
ϕ	0.5	Health Costs per Pollution Emitted
$\bar{P}$	10	National Threshold
c	1.1%	Cost of Capital

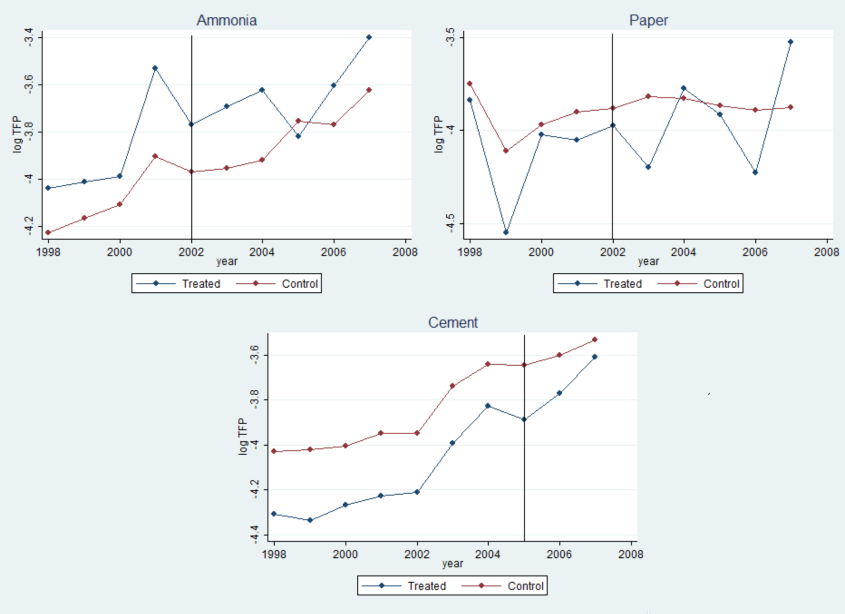
No attempt has been made to calibrate the model. The simulation serves only as an illustration to the model we develop in Naso and Swanson (2017). To keep differences in taxes across development zones relatively low, we set average productivity to decrease following the equation: $A^r = A^1 \cdot 0.8^{r-1}$.

Figure 9: Log TFP distribution of Chinese cities in 1998



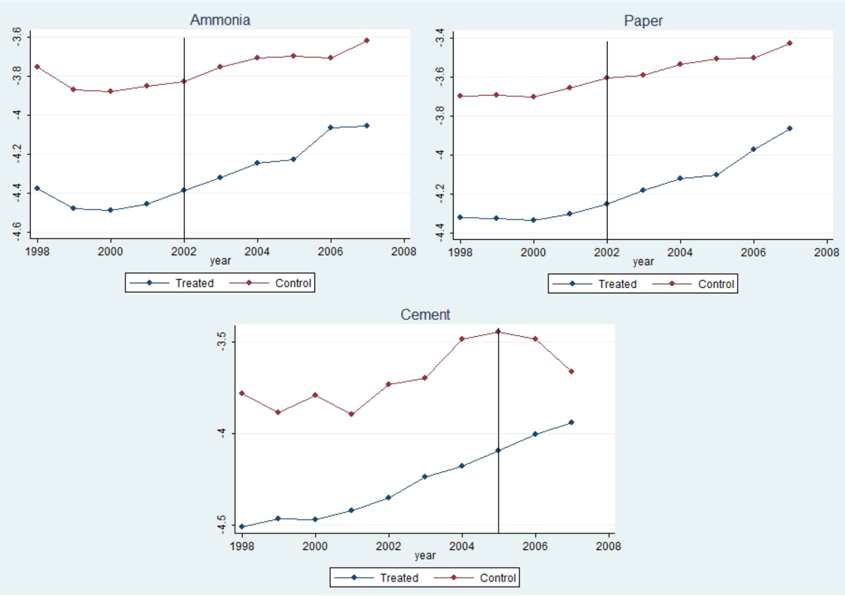
City-productivity distribution in 1998. This distribution was constructed by calculating the log average TFP of every firm in each city in China in 1998.

Figure 10: Standard Porter hypothesis: TFP trends



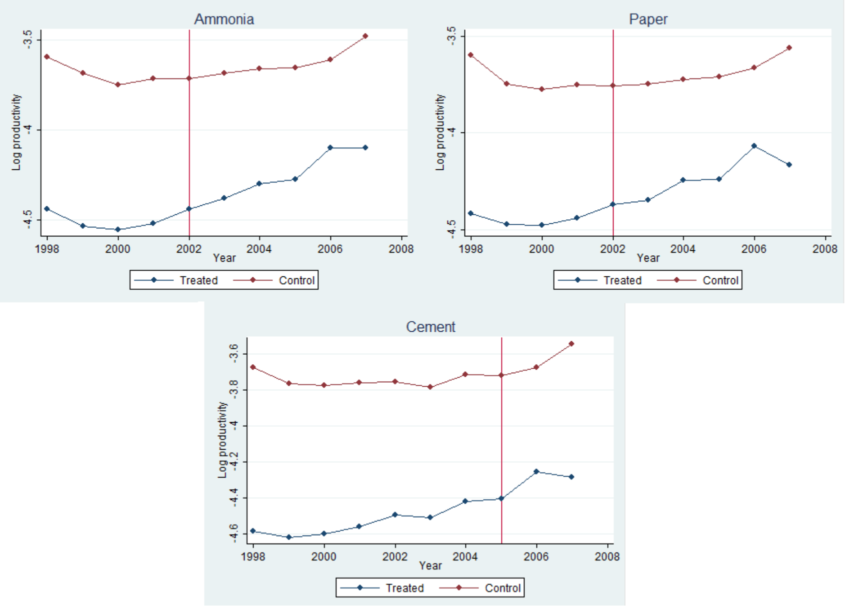
Log TFP trends pre treatment for treated and control industries.

Figure 11: Log TFP trends for treated and untreated industries



Log TFP trends pre treatment for treated and control industries.

Figure 12: Log TFP trends for the same industries in different cities



Log TFP trends pre treatment for treated and control industries.

Table 8: Placebo: NPS on TFP of regulated firms in developing cities

Variable	**Coefficient**	**(Std. Err.)**
δ_a	0.078***	(0.018)
δ_p	0.035	(0.023)
δ_c	0.039**	(0.018)
K_{ict}	0.005**	(0.003)
soe_{ct}	-0.019***	(0.005)
sez_{ct}	-0.001	(0.009)
$ages_{ict}$	-0.004	(0.002)
$assets_{ict}$	0.007**	(0.003)
Obs	146,901	
R^2	0.66	

Standard errors are clustered by city and industry.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 9: Placebo: Regulated industries in different cities

Variable	**Coefficient**	**(Std. Err.)**
$\delta_{a,25th}$	0.193***	(0.039)
K_{ict}	0.005	(0.013)
soe_{ct}	0.051**	(0.023)
sez_{ct}	-0.006	(0.042)
$ages_{ict}$	0.003	(0.019)
$assets_{ict}$	0.017	(0.014)
Obs	2,329	
R^2	0.72	
$\delta_{p,25th}$	0.027	(0.022)
K_{ict}	0.026***	(0.009)
soe_{ct}	-0.019	(0.037)
sez_{ct}	0.026	(0.048)
$ages_{ict}$	-0.047	(0.029)
$assets_{ict}$	0.005	(0.012)
Obs	2,806	
R^2	0.60	
$\delta_{c,25th}$	0.028	(0.019)
K_{ict}	0.019*	(0.011)
soe_{ct}	-0.045*	(0.025)
sez_{ct}	-0.021	(0.067)
$ages_{ict}$	-0.007	(0.014)
$assets_{ict}$	0.016	(0.019)
Obs	3,581	
R^2	0.70	

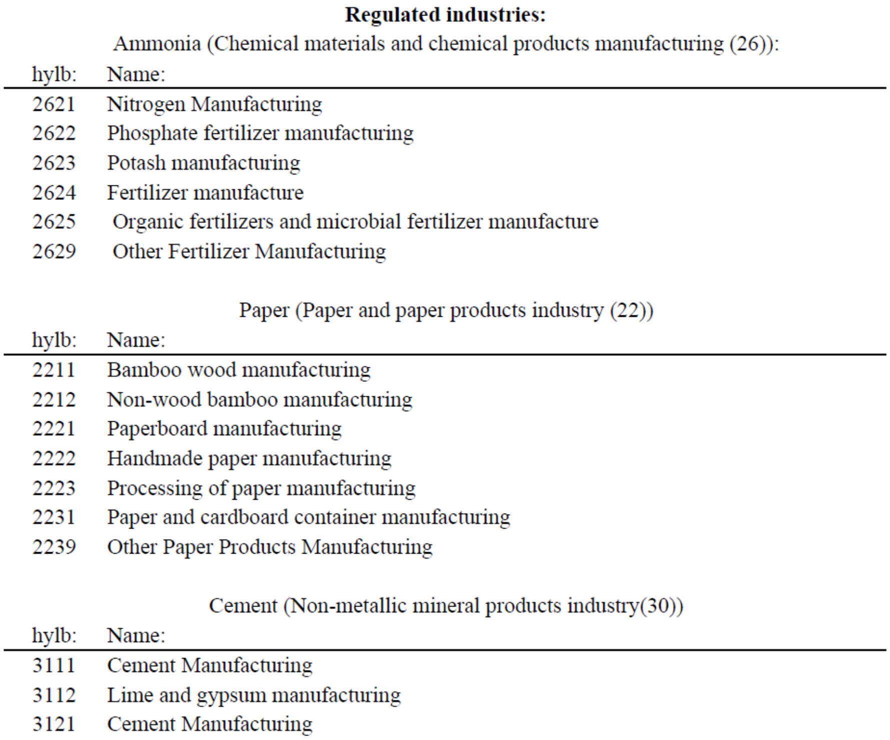
Standard errors are are clustered by city.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 10: Workforce

Variable	**Coefficient**	**(Std. Err.)**
$\delta_{a,25th}$	-0.025	(0.090)
soe_{ct}	0.255**	(0.112)
sez_{ct}	0.022	(0.212)
$ages_{ict}$	0.824***	(0.189)
Obs	2,394	
R^2	0.74	
$\delta_{p,25th}$	0.388*	(0.205)
soe_{ct}	0.048	(0.043)
sez_{ct}	0.6748***	(0.153)
$ages_{ict}$	0.659***	(0.153)
Obs	2,881	
R^2	0.63	
$\delta_{c,25th}$	-0.038	(0.172)
soe_{ct}	-0.049	(0.095)
sez_{ct}	-0.339	(0.313)
$ages_{ict}$	0.561***	(0.139)
Obs	3,661	
R^2	0.77	

Standard errors are are clustered by city.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Figure 13: 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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