Appendix A: Theoretical Frameworks

1. How the vertical reforms lead to stricter environmental regulation via internalizing pollution spillovers.

Consider a hypothetical Chinese city with $N \geq 1$ districts in its boundary. Due to pollution externality, pollution level in district $i \in \{1, \dots, N\}$ is jointly determined by the pollutant emissions in all the districts, that is,

$$\mathrm{Pollut}_i = \frac{1}{N}\sum_i E_i(y_i, a_i), \qquad [A1]$$

where Pollut_i, E_i, y_i, and a_i stand for the pollution level, pollutant emission, GDP and abatement investment in the district, respectively.

Before the vertical reform, the government of each district controls the environmental policies in the district, and chooses its optimal stringency of regulation, λ_i, to maximize its utility as follows,

$$U_i = y_i - \mathrm{Pollut}_i, \qquad [A2]$$

The first-order condition of maximizing [A2] can be calculated as,

$$\frac{\partial y_i}{\partial \lambda_i} = \frac{1}{N}\left(\frac{\partial E_i}{\partial y_i}\frac{\partial y_i}{\partial \lambda_i} + \frac{\partial E_i}{\partial a_i}\frac{\partial a_i}{\partial \lambda_i}\right). \qquad [A3]$$

After the vertical reform, the city government takes over the environmental policies in

all the districts, and chooses the optimal stringency of regulation in each district, $\lambda_{i\in\{1,\ldots,N\}}$, to maximize the following utility function,

$$U = \frac{1}{N}\sum_i y_i - \frac{1}{N}\sum_i \mathrm{Pollut}_i. \qquad [A4]$$

The first-order condition of maximizing [A4] is as follows,

$$\frac{\partial y_i}{\partial \lambda_i} = \frac{\partial E_i}{\partial y_i}\frac{\partial y_i}{\partial \lambda_i} + \frac{\partial E_i}{\partial a_i}\frac{\partial a_i}{\partial \lambda_i}, \quad \forall i \in \{1, \ldots, N\}. \qquad [A5]$$

Assume that the technology of clean production is given, so that $0 < \frac{\partial E_i}{\partial y_i} = \delta < 1$. Stricter environmental regulation leads to increased abatement investment, which further results in decreased pollutant emissions, i.e., $\frac{\partial a_i}{\partial \lambda_i} > 0$, $\frac{\partial E_i}{\partial a_i} < 0$. Both environmental regulation and abatement investments exhibit diminishing marginal returns, that is, $\frac{\partial^2 a_i}{\partial \lambda_i^2} < 0$, $\frac{\partial^2 E_i}{\partial a_i^2} > 0$. Environmental regulation affects the GDP of the city negatively and in an increasing manner, i.e., $\frac{\partial y_i}{\partial \lambda_i} < 0$, $\frac{\partial^2 y_i}{\partial \lambda_i^2} < 0$. Then comparing [A3] and [A5] shows that the stringency of environmental regulation, λ_i, by the city government after the vertical reform will be *greater* than the regulation by the district government before the reform when $N \geq 2$. The intuition is straightforward: the city government will internalize pollution spillovers among different districts within the city when making environmental policies, which results in stricter environmental regulation than the regulation previously determined by the district governments before the reform.

Note that in this model, there is no incentive incompatibility between the city and district governments in environmental protection since they have almost the same utility functions. If we model the city government to care more about the environment than the district governments so that the weight of pollution in the utility function of the city government is greater than that of the district governments, it can then be shown that the stringency of environmental regulation by the city government is even greater after the vertical reform.

2. How the increased stringency of environmental regulation caused by the vertical reforms results in decreased firm TFP?

In this part, we provide a simple theoretical framework that shows how industrial firms adjust their production and abatement decisions upon stricter environmental regulation after the vertical reforms, which then affects their TFP negatively. Suppose that in a competitive market, there is a typical industrial firm with a Cobb-Douglas production function, $Q(K, L) = AK^{\alpha}L^{1-\alpha}$, where A, K, L represent production technology, capital stock and labor, respectively, and $\alpha \in (0,1)$ is a constant.

The production process not only produces valuable goods, but also generates hazardous pollutant emissions that are an increasing function of the output Q. Meanwhile, the firm employs additional (non-productive) capital K_e and labor L_e in pollution treatment, which can otherwise be used in the production. So the firm's emission level is jointly determined by the output Q and abatement inputs K_e and L_e, which is assumed to have a Cobb-Douglas functional form as follows, $E(Q, K_e, L_e) = BQ^{\beta}K_e^{\gamma}L_e^{\delta}$, where B stands for abatement technology, $\beta > 1$, $\gamma < 0$, and $\delta < 0$. Thus, $\frac{\partial E}{\partial Q} > 0$, $\frac{\partial^2 E}{\partial Q^2} > 0$; $\frac{\partial E}{\partial K_e} < 0$, $\frac{\partial^2 E}{\partial K_e^2} > 0$; $\frac{\partial E}{\partial L_e} < 0$, $\frac{\partial^2 E}{\partial L_e^2} > 0$. The second-order conditions imply increasing marginal emissions of the output and decreasing marginal returns on pollution abatement.

Environmental regulation is modeled as a quantity tax, λ, on each unit of pollutant emissions. Then the firm chooses its optimal K, L, K_e, and L_e to maximize its profits:

$$\mathrm{MAX}_{k,L,K_e,L_e}\ \pi = p \cdot AK^{\alpha}L^{1-\alpha} - r \cdot (K + K_e) - w \cdot (L + L_e) - \lambda \cdot BQ^{\beta}K_e^{\gamma}L_e^{\delta}, \qquad [A6]$$

where p, r and w are market price of the output, rental price of capital stock, and wage rate of labor, respectively.

The first order conditions for maximizing the profit in [A6] can be calculated as follows:

$$\frac{\partial \pi}{\partial K} = pA\alpha K^{\alpha-1}L^{1-\alpha} - r - \lambda BA^{\beta}\alpha\beta K^{\alpha\beta-1}L^{(1-\alpha)\beta}K_e^{\gamma}L_e^{\delta} = 0, \quad [A7]$$

$$\frac{\partial \pi}{\partial L} = pA(1-\alpha)K^{\alpha}L^{-\alpha} - w - \lambda BA^{\beta}(1-\alpha)\beta K^{\alpha\beta}L^{(1-\alpha)\beta-1}K_e^{\gamma}L_e^{\delta} = 0, \quad [A8]$$

$$\frac{\partial \pi}{\partial K_e} = -r - \lambda BA^{\beta}\gamma K^{\alpha\beta}L^{(1-\alpha)\beta}K_e^{\gamma-1}L_e^{\delta} = 0, \quad [A9]$$

$$\frac{\partial \pi}{\partial L_e} = -w - \lambda BA^{\beta}\delta K^{\alpha\beta}L^{(1-\alpha)\beta}K_e^{\gamma}L_e^{\delta-1} = 0. \quad [A10]$$

Using [A7]-[A10], we get the following results:

$$\frac{\partial K}{\partial \lambda} < 0,\ \frac{\partial L}{\partial \lambda} < 0,\ \frac{\partial K_e}{\partial \lambda} > 0,\ \frac{\partial L_e}{\partial \lambda} > 0; \quad [A11]$$

$$\frac{1}{E}\frac{\partial E}{\partial \lambda} < \frac{1}{Q}\frac{\partial Q}{\partial \lambda} < 0; \quad [A12]$$

$$\frac{1}{Q}\frac{\partial Q}{\partial t} < \frac{1}{K+K_e}\frac{\partial (K+K_e)}{\partial \lambda}; \quad [A13]$$

$$\frac{1}{Q}\frac{\partial Q}{\partial t} < \frac{1}{L+L_e}\frac{\partial (L+L_e)}{\partial \lambda}. \quad [A14]$$

Then, we are ready to analyze the change of firm TFP when the stringency of environmental regulation goes up. The firm's TFP is defined as $TFP = \frac{Q}{(K+K_e)^{\alpha}(L+L_e)^{1-\alpha}}$. Taking logarithm on both sides of the latter equation and taking derivative implies that $\frac{1}{TFP}\frac{\partial TFP}{\partial \lambda} = \frac{1}{Q}\frac{\partial Q}{\partial \lambda} - \alpha\frac{1}{K+K_e}\frac{\partial (K+K_e)}{\partial \lambda} - (1-\alpha)\frac{1}{L+L_e}\frac{\partial (L+L_e)}{\partial \lambda} < 0$, where the inequality follows from [A13] and [A14]. Thus, stricter environmental

regulation leads to decreased firm TFP since the firm has to set aside more capital and labor for non-productive pollution abatement, which can otherwise be used in the production.

In addition, we can analyze the change of the firm's emission level and intensity upon increased stringency of environmental regulation. For the emission level, using $E(Q, K_e, L_e) = BQ^{\beta}K_e^{\gamma}L_e^{\delta}$ implies that $\frac{1}{E}\frac{\partial E}{\partial \lambda} = \beta\frac{1}{Q}\frac{\partial Q}{\partial \lambda} + \gamma\frac{1}{K_e}\frac{\partial K_e}{\partial \lambda} + \delta\frac{1}{L_e}\frac{\partial L_e}{\partial \lambda} < 0$, where the inequality follows from using [A11], [A12], and $\beta > 1$, $\gamma < 0$, $\delta < 0$. So the firm's emission level decreases upon stricter environmental regulation. For the firm's emission intensity, define $\rho = \frac{E}{Q}$; then using [A12] implies that $\frac{1}{\rho}\frac{\partial \rho}{\partial \lambda} = \frac{1}{E}\frac{\partial E}{\partial \lambda} - \frac{1}{Q}\frac{\partial Q}{\partial \lambda} < 0$, suggesting decreased emission intensity upon increased stringency of environmental regulation.

Appendix B: How the data on China's vertical reforms are collected

To the best of our knowledge, there is no existing literature having documented in detail when and where China's vertical reforms have taken place. So we manually collect the information on the vertical reforms for each of 283 prefecture-level cities in China from various sources. By keyword search, we find the text files about China's vertical reforms, from which we can figure out which Chinese cities have implemented the reforms during 1994-2007 and when.[1] We can also figure out which districts in a partially reformed city have been involved in the reforms. The sources where we conduct the keyword search are listed as follows.

1. Official documents of local governments

In 2002, Shaanxi Province of China published *the directive on reforming EPBs at the city and lower levels in Shaanxi province*, which requires all the cities in Shaanxi Province to undertake full vertical reforms. That is, all the local EPBs at the district/county level in Shaanxi Province will become direct branches of the EPBs at the city level after the reform. The city EPBs also begin to take charge of the human resources, funding, and asset management of the local EPBs at the district/county level.

In addition, some other Chinese cities (such as Hengshui, Jiangmen, and Shantou,

[1] The key words used in the search include *vertical reforms* ("Chuizhi Gaige"), *vertical management* ("Chuizhi Guanli"), *organization of EPBs* ("Huanbaoju Jigou Shezhi"), *restructuring of organizations* ("Jigou Bianzhi Gongzuo"), *new branches of city EPBs* ("Huanbao Paichu Jigou Shidian"), *reforms of EPBs* ("Huanbao Jigou Gaige"), *organizational development of EPBs* ("Jigou Jianshe"), and *agency* ("Paichu Jigou") among others. We choose the period of 1994-2007 because the first vertical reform in China happened in 1994 (in Dalian) and 2007 is the last year of our sample.

etc.) have also issued official documents, which explicitly declared the plans for the (partial) vertical reforms, including which districts/counties in the city will be subject to the reforms.

2. Various yearbooks during 1994-2007

These yearbooks include *China's environmental yearbooks*, environmental yearbooks of different Chinese cities, and the yearbooks of different Chinese provinces/cities. The yearbooks have documented important environmental policies and reforms in China, including the vertical reforms at the city level. Below are some snapshots of the paragraphs in these yearbooks that have described the vertical reforms in some Chinese cities.

e.g., 1: The vertical reforms in Hefei and some other Chinese cities (source: the 1996 *China's environmental yearbook*, Page 242)

【环保派出机构试点】 随着全国经济形势的发展和环保工作的开拓，全国环境管理体制改革也在不断深化。为加强城市环境保护工作的整体性和统一性，在大连市进行环保派出机构试点运行一年多的基础上，国家环保局于1995年组织召开了由全国各省会城市环保部门参加的"城市辖区环保派出机构设置试点工作研讨会"，明确了只要有利于促进环保机构建设、有利于强化环保统一监督管理职能、有利于健全环保执法队伍，就必须抓住机遇、开拓试点的工作思路。

在1995年的地方机构改革中，经过努力，已有大连市、合肥市、荆沙市、南平市、德州市、临沂市等部分城市完成了在其市辖区设置环保派出机构的试点工作，厦门市、杭州市、沈阳市、西安市、深圳

e.g., 2: The vertical reform in Jingzhou (source: the 1998 *China's environmental yearbook*, Page 413)

【机构建设】 全省环保系统机关和事业单位总数达351个，其中地、市、县（区）独立环保局有89个，占全省113个地、市、县（区）的78.8%；职工总数达到5262人，其中科技人员2743人。荆州市环保局在其所属3个城区设立了环保分局，实行了人、财、物由市局统一管理的体制。省环保局积极着手进行全省

e.g., 3: The vertical reform in Ningbo (source: the 2002 *China's environmental yearbook*, Page 454)

【自身能力建设】 2001年，经过公开考试和竞争上岗、组织考察和公示，市环保局选拔了一批年轻人担任中层干部，并对局系统中层领导人选作了适当的调整，充实了环保队伍的中坚力量。同时，在市政府的关心和支持下，10月份，海曙、江东、江北三区环保分局授牌成立，这是宁波环保事业的进步。2001

e.g., 4: The vertical reform in Zhanjiang (source: the 2004 *China's environmental yearbook*, Page 851)

湛江市环保局是于1986年在原湛江地区环境保护办公室基础上组建起来的，1996年升格为正处级单位并进入政府序列。2001年完成机构改革，内设科室6个：办公室、法制科、规划财务科、污染控制科、监督管理科、生态保护科；直属单位8个：麻章分局、坡头分局、东海岛分局、总工程师室、市环境监理所、市环境保护监测站、市环保信息宣教中心、市环境科学技术研究所，形成了一个比较完善的环境管理体系。

e.g., 5: The vertical reforms in Datong and Taiyuan (source: the 2003 *Yearbook of Shanxi Province*, Page 631)

【机构改革】 在县级机构改革中，全省119个县（市区）中有74个设置了独立环保局，两个设置了独立环保事业单位，太原、大同两市的10个辖区设置了市环保局分局，另有五台山风景名胜区和两个开发区设置了独立环保局。全省县级环保机构比省编办明确要求设置的环保机构增加了7个。全省环保机构基本保持稳定。

e.g., 6: The vertical reform in Jiaozuo (source: the 2002 *Yearbook of Jiaozuo City*, Page 271)

【环保机构改革】 2001年，市环保局根据市委常委会议决定，对四城区环保局实行垂直管理。各县（市）区环保机关全部得到保留，环保人员工资经费列入当地财政预算。市环保局在科室调整中增设

e.g., 7: The vertical reform in Xingtai (source: the 2005 *Yearbook of Xingtai City*, Page 124)

动物防疫监督防护网络体系。完成市区环保管理体制改革工作。加强市区环境保护统一管理，在深入调研，彻底澄清桥东区、桥西区和开发区环保机构设置和人员编制现状的基础上，制订印发了《关于桥东区、桥西区、开发区环保局管理体制调整有关问题的通知》（邢机编办字〔2004〕45号），将"三区"环保工作管理体制由原来的属地管理改革为市、区双重管理，以市管理为主，进一步理顺了工作关系。组建了南水北调工

3. Official websites of local governments/EPBs

Although most of the vertical reforms in China have been recorded in the above yearbooks, in some cases, the reforms are only briefly described in the yearbooks. Then we look for detailed information about the vertical reforms from the official websites of local governments/EPBs, where the information disclosure section documents in detail the evolving of local EPB system, including the description of the vertical reforms, if any. Below are some snapshots of the web pages that contain the information on the evolving and reforms of local EPBs in some Chinese cities.

e.g., 8: The information about a local EPB at the district level in Zhangjiakou city

(Source: http://www.zjk.gov.cn/govaffair/content.jsp?code=755493237/2010-00036.)

索 引 号: 755493237/2010-00036
发布机构: 环境保护分局,null
名　称: 张家口市桥东区环境保护分局主要工作职责
文　号:
主题分类: 城乡建设、环境保护
发文日期: 2008年01月01日
主 题 词:

张家口市桥东区环境保护分局主要工作职责

张家口市桥东区环境保护分局成立于2003年11月18日。内设科（队）：办公室、计划财务科、污染控制科（科技产业标准科）、环境督查管理科（自然生态保护科）、法规宣教科、稽查队、环境监测站及环境监察大队。

e.g., 9: The information about a local EPB at the district level in Hebi city

(Source: http://www.hbhsq.gov.cn/xinxgk/zfjg/czbm/hbj/gk/2015-05-28/1526.html.)

e.g., 10: The information about the vertical reform in Liaoyang city

(Source:http://sthj.ln.gov.cn/xxgkml/xxdt/sxdt/201104/t20110413_31332.html?keywords=%E5%9E%82%E7%9B%B4%E7%AE%A1%E7%90%86.)

e.g., 11: The information about the vertical reform in Shenyang city

(Source: http://www.syepb.gov.cn/data/2013_01_21/201312115208.html.)

首页 -> 环保体系 -> 环保大事记

沈阳市环境保护局历史与现状

2013-1-21 15:21:54

一、环境保护机构改革历史沿革

1979年12月，沈阳市正式成立沈阳市环境保护局，人员编制39人；1983年1月，沈阳市党政机关机构改革，市环境保护局与市环境卫生局合并为市环境管理局；1985年4月，市政府将环境卫生业务划归市城市建设管理局，独立设置市环境保护局，列为政府组成部门。2008年4月，实现了市区垂直管理（4个县除外），增加了4个区级管理机构。我市有独立建制的环境保护机构18个（包括市环保局及13个分局、4个县（市）环保局）。市环保局设置环境监察、环境科研、环境监测、环境技术评估、环境宣传教育、环境信息等15个事业单位。

二、环境保护机构建设

根据市委、市政府关于加强环境保护和生态市建设的有关精神，为进一步加强我市环境保护管理工作，2008年4月底，我市环境保护管理体制进行了调整，市环保局对各区、开发区环保机构实行了垂直管理，为市环保局直属机构，同时也是各区政府的工作部门和开发区管委会的内设机构。我市环保

4. News media, Baidu encyclopedia, and academic literature

Finally, to double check if the collected information is complete and accurate, we find the entries on China's vertical reforms in news media (e.g., China environmental news, daily news of Chinese cities), Baidu encyclopedia (www.baike.baidu.com), and Chinese academic literature (http://www.cnki.net/). If some information is still missing, we also contact officials in local EPBs at the city level for further information. Below are some examples.

e.g., 12: A report about the vertical reform in Harbin (reported by the Daily News of Harbin)

(Source: http://news.sina.com.cn/c/2007-10-27/032312794364s.shtml.)

市区环保系统实行垂直管理

http://www.sina.com.cn 2007年10月27日03:23 哈尔滨日报

哈尔滨新闻网讯（梅广欣 记者 叶滨）记者从市环保局获悉，为提高对环境保护的管理力度和办事效率，哈尔滨市环保系统日前进行了市区环境管理体制垂直管理改革，首批实行垂直管理的范围为哈尔滨市辖区（不含呼兰区和阿城区）。

据了解，这次改革是在市委、市政府的直接领导下进行的。按照省编办要求，先在哈尔滨市辖区(不含呼兰区、阿城区)进行环保机构垂直管理试点，待各方面条件成熟时，再对县(市)一级环保机构管理体制进行调整。

e.g., 13: The information about a local EPB at the district level in Shangqiu (obtained from the Baidu encyclopedia)

(Source: https://baike.baidu.com/item/商丘市环保局梁园分局/13974556.)

商丘市环保局梁园分局 编辑

本词条缺少**概述图**，补充相关内容使词条更完整，还能快速升级，赶紧来编辑吧！

商丘市环保局梁园分局，该局成立于1984年5月， 1997年撤地设市后改称梁园区环境保护局，2003年上划后称商丘市环保局梁园分局。

e.g., 14: The information on the vertical reform in Liaoyuan (derived from a Chinese academic paper).

(Source: Tian, Z.B., and Y.M. Zhou. 2009. "Policy implications from the vertical environmental reform in Liaoyuan city." *China Environmental Management*, issue 4. In Chinese)

In an academic paper, Tian and Zhou (2009) reveal that "In July 2001, the

government of Liaoyuan city undertook a vertical environmental reform. After that, the local EPBs in the Longshan and Xi'an districts were merged into the EPB of Liaoyuan city, and became two branches of the city EPB. The management of the two local EPBs was also transferred to the city EPB."

Appendix C: Additional figures and tables

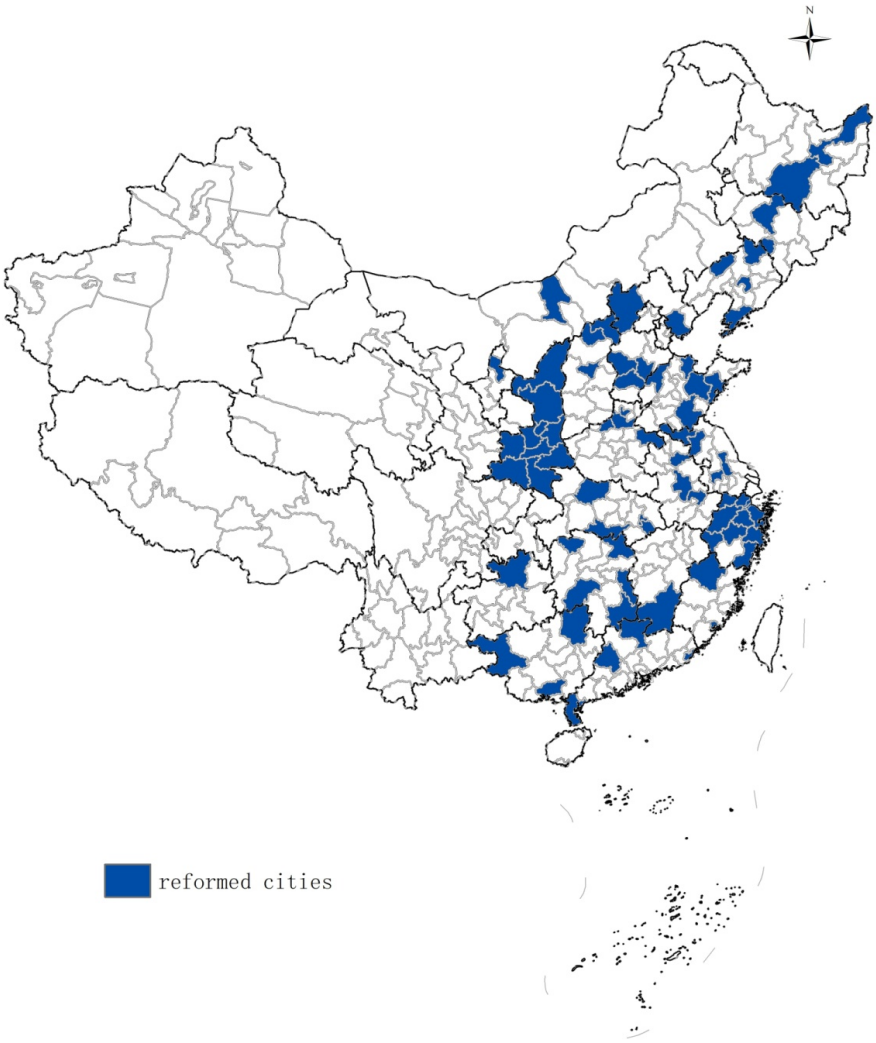


Figure A1: Chinese cities that undertook vertical reforms during 1994-2007

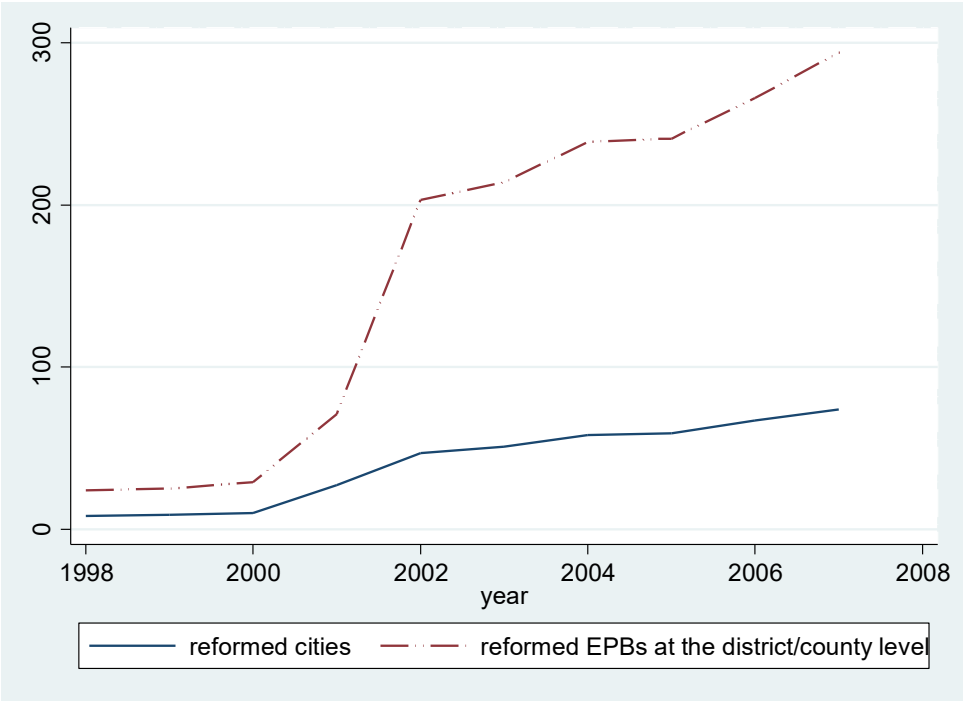
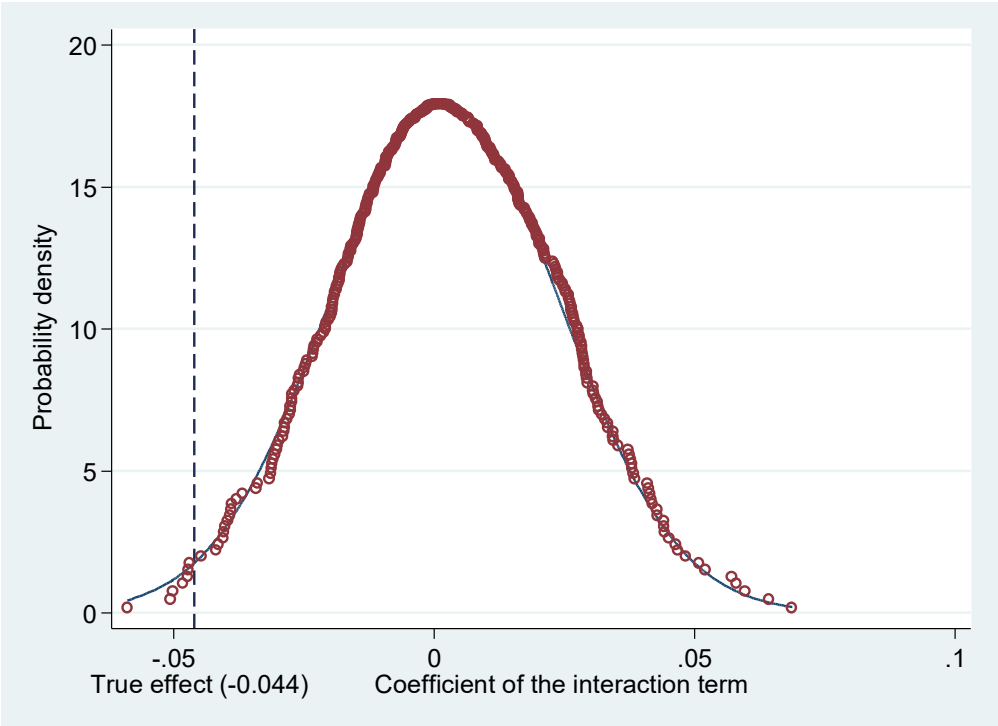


Figure A2: The number of reformed cities and local EPBs across years



Notes: The procedure of the placebo test is as follows: first, in each year between 1998 and 2007, based on the number of Chinese cities that started the true reforms in the year, we randomly select (without replacement) the cities that start the fake reforms in that year. Second, in each year, we calculate the proportion of firms being subject to the true reforms in the cities that started the reforms in the year. Then, in the cities that start the fake reforms in that year, we randomly choose that proportion of firms to be subject to the fake reforms. Lastly, based on the constructed fake vertical reforms, we construct a dummy, I[verti_fake], and estimate the effects of the fake reforms using (3) and I[verti_fake]. The procedure is repeated 500 times and the distribution of 500 estimated γ in (3) is illustrated in the figure (each circle represents an estimated γ). The vertical dashed line represents the true effect of the reforms, -0.044, in column 7 of Table 2.

Figure A3: The distribution of γ in (3), a placebo test

Table A1: The difference between unreformed vs. reformed districts/counties in the cities that ever undertook vertical reforms

	(1)	(2)
Variables	**Unreformed districts/counties**	**Reformed districts/counties**
Proportion of SOEs	0.21	0.324***
	(0.0087)	(0.0084)
Proportion of foreign-owned firms	0.091	0.118***
	(0.0047)	(0.0048)
Average wage rate	9.207	10.438***
	(0.188)	(0.198)
Average firm size, by labor	291.06	423.65***
	(23.01)	(19.07)
Average firm size, by capital stock	28795.53	46659.25***
	(4706.34)	(3286.59)
Average firm age	11.79	15.13***
	(0.188)	(0.226)
Average output value per firm	258.41	251.56
	(7.509)	(6.181)

Notes: We divide each partially reformed city into two parts – the districts/counties that ever experienced vertical reforms during 1998-2007 and the other unreformed districts/counties. Using *annual surveys of industrial firms* in China, we construct variables for each part of a partially reformed city in each year; the means of the variables are displayed with standard deviations in parentheses. ***, ** and * indicate that the means in columns 1 vs. 2 are statistically different at the 1%, 5% and 10% significance levels, respectively.

Table A2: List of polluting vs. non-polluting industries

Polluting industries		Non-polluting industries	
Industry	Code	Industry	Code
Agricultural product and by product processing	13	Cigarette products	16
Food	14	Clothes, shoes and caps	18
Beverage	15	Timber, bamboo, cane and straw products	20
Textile	17	Furniture	21
Leather, fur and feather products	19	Printing and record medium production	23
Paper	22	Educational and sports products	24
Petroleum, coke and nuclear fuel processing	25	Plastic products	30
Chemical materials and products	26	Fabricated metal products	34
Pharmaceutical products	27	General equipment manufacturing	35
Chemical fiber manufacturing	28	Specialized equipment manufacturing	36
Rubber products	29	Transportation equipment	37
Non-metallic mineral products	31	Electric devices and apparatus	39
Ferrous metal smelting and rolling	32	Computers, communication and other electronic equip.	40
Non-ferrous metal smelting and rolling	33	Instruments, meters, cultural and office machinery	41
		Craftwork products	42
		Resources and waste materials recycling	43

Notes: The 2-digit industrial codes are based on China's industrial classification for national economic activities (GB/T 4754-2002). We define the polluting vs. non-polluting industries based on a Chinese legal document – *Industry Catalogue for environmental audit of listed companies* (the Ministry of Environmental Protection of China, 2008).

Table A3: Calculated pollution intensities, 30 2-digit industries

Industrial code (2-digit)	**Industrial sectors**	**Pollution intensities (in percentage)**
16	Cigarette products	0.032
40	Computers, communication and other electronic equip.	0.035
39	Electric devices and apparatus	0.061
21	Furniture	0.075
18	Clothes, shoes and caps	0.076
36	Specialized equipment manufacturing	0.079
30	Plastic products	0.086
24	Educational and sports products	0.093
35	General equipment manufacturing	0.096
42	Craftwork products	0.101
37	Transportation equipment	0.101
29	Rubber products	0.105
23	Printing and record medium production	0.106
34	Fabricated metal products	0.118
32	Ferrous metal smelting and rolling	0.146
13	Agricultural product and by product processing	0.146
19	Leather, fur and feather products	0.146
20	Timber, bamboo, cane and straw products	0.151
41	Instruments, meters, cultural and office machinery	0.181
15	Beverage	0.183
14	Food	0.191
27	Pharmaceutical products	0.251
33	Non-ferrous metal smelting and rolling	0.259
25	Petroleum, coke and nuclear fuel processing	0.292
26	Chemical materials and products	0.311
31	Non-metallic mineral products	0.338
17	Textile	0.343
28	Chemical fiber manufacturing	0.364
43	Resources and waste materials recycling	0.385
22	Paper	0.71

Notes: The pollution intensity of each 2-digit industrial sector is calculated as the total pollution discharge fees in the sector divided by the total value added in the sector. We use the 2004 *annual survey of industrial firms* in China to calculate the pollution intensities of 30 2-digit industrial sectors.

Table A4: Balancing checks

Variables	**(1)**	**(2)**	**(3)**	**(4)**
	Treatment group	Control group	Unconditional diff.	Conditional diff.
Panel A: Selection variables for the reforms				
If district (0-1)	0.545	0.067	0.478	
	(0.498)	(0.25)	(0.031)***	
Proportion of the district/county's industrial	0.138	0.078	0.059	
production in the city 1998	(0.189)	(0.084)	(0.011)***	
Proportion of the district/county's production	0.134	0.082	0.051	
of polluting industries in the city 1998	(0.19)	(0.092)	(0.012)***	
Proportion of the district/county's industrial	0.151	0.065	0.085	
production by SOEs in the city 1998	(0.222)	(0.088)	(0.013)***	
Panel B: Other characteristics				
Fiscal expenditure/revenue 1998	1.633	1.706	-0.073	0.073
	(0.781)	(0.667)	(0.072)	(0.088)
Yearly PM2.5 1998	36.03	28.093	7.936	3.045
	(10.594)	(8.293)	(1.19)***	(2.25)
Proportion of export value in industrial	0.087	0.114	-0.026	-0.018
production 1998	(0.122)	(0.157)	(0.011)**	(0.015)
Proportion of foreign-owned firms	0.088	0.066	0.021	0.01
in the district/county 1998	(0.132)	(0.094)	(0.009)**	(0.01)
Average wage weighted by labor 1998	6.267	5.554	0.713	0.279
	(5.915)	(2.737)	(0.372)*	(0.455)
Average capital stock of firms 1998	36794.33	16323.68	20470.65	4449.44
	(82318.67)	(23452.02)	(4889.49)***	(4984.6)
Average age of firms 1998	17.808	15.748	2.059	0.844
	(6.794)	(5.71)	(0.505)***	(0.81)
Average labor productivity	102.048	107.805	-5.757	-4.757
weighted by labor 1998	(125.952)	(74.357)	(8.34)	(9.73)
Herfindahl-Hirschman index 1998	0.203	0.142	0.061	0.005
	(0.145)	(0.087)	(0.012)***	(0.22)

Notes: This table reports summary statistics of districts/counties in the Chinese cities that ever experienced the vertical reforms during 1994-2007. The treatment group refers to the districts/counties that were reformed during the period; the control group refers to the other districts/counties in the cities. Panel A compares the treatment and control groups on the selection variables that are correlated with the assignment of the reforms. Panel B demonstrates the comparison of other district/county-level variables in the first year of the sample (1998) between the treatment and control groups. Columns 1 and 2 present the means and standard deviations (in parentheses) of the variables. Column 3 shows their unconditional difference between the treatment and control groups. Column 4 analyzes the conditional difference by regressing the variables in Panel B on a treatment dummy controlling for city fixed effects and the selection variables in Panel A. Coefficients of the treatment dummy are presented with robust standard errors in parentheses. ***, ** and * stand for 1%, 5% and 10% significance

levels, respectively.

Table A5: Effects of China's vertical reforms on firm TFP, dynamic analysis

	(1)	(2)	(3)
Time lag (N)	**0**	**1**	**2**
I[verti]	0.021	0.024	-0.035
	(0.023)	(0.034)	(0.047)
I[verti] × I[pollut]	**-0.046**	**-0.054**	**-0.046**
	(0.02)**	**(0.03)***	**(0.041)**
Fixed effects			
Firm	Yes	Yes	Yes
City-year	Yes	Yes	Yes
Sector-year	Yes	Yes	Yes
Additional controls			
Firm characteristics	Yes	Yes	Yes
Treatment trends	Yes	Yes	Yes
Control × Year dummy	Yes	Yes	Yes
Obs.	1,138,709	914,056	701,240

Notes: The dependent variable is log TFP. In columns 2-3, the current and all the lagged I[verti] and I[verti] × I[pollut] up to N periods are included in the specification (3). The firms whose observations are less than 3 years are dropped. Standard errors clustered at the city level are used in the estimation. The summed coefficients of the current and all the lagged I[verti] (I[verti] × I[pollut]) are reported; standard errors of the summed coefficients are in parentheses. ***, ** and * indicate 1%, 5% and 10% statistical significance levels, respectively. Firm characteristics include status of export (0-1), capital-labor ratio, status of SOE (0-1), and real capital stock (in logs). Treatment trends include linear and quadratic trends of the reformed districts/counties as a whole. "Control" refers to the selection variables that determine the assignment of reformed districts/counties in a city.

Table A6: The role of firm affiliation

	(1)	(2)	(3)	(4)	(5)
Subsample	Full sample	Excluding affiliation to central, provincial governments	Excluding affiliation to central, provincial, city, district/county governments	Excluding affiliation to central, provincial, city, district/county, township governments	Excluding affiliation to central, provincial, city, district/county, township, community/village governments
I[verti]	0.027	0.033	0.035	0.008	-0.003
	(0.03)	(0.031)	(0.034)	(0.033)	(0.035)
I[verti] × I[pollut]	**-0.049**	**-0.051**	**-0.072**	**-0.08**	**-0.089**
	(0.027)*	**(0.028)***	**(0.031)****	**(0.028)*****	**(0.034)****
Fixed effects					
Firm	Yes	Yes	Yes	Yes	Yes
City-year	Yes	Yes	Yes	Yes	Yes
Sector-year	Yes	Yes	Yes	Yes	Yes
Additional controls					
Firm characteristics	Yes	Yes	Yes	Yes	Yes
Treatment trends	Yes	Yes	Yes	Yes	Yes
Control × Year dummy	Yes	Yes	Yes	Yes	Yes
Obs.	200,751	193,479	141,735	96,237	84,431

Notes: The dependent variable is log TFP. Subsamples in columns 2-5 are based on firms' affiliation in the year before the year of reform. The full sample only contains the firms in the ever-reformed cities and new firms entering the sample after the year of reform are dropped. Standard errors clustered at the city level are in parentheses. ***, ** and * indicate 1%, 5% and 10% statistical significance levels, respectively. Firm characteristics include status of export (0-1), capital-labor ratio, status of SOE (0-1), and real capital stock (in logs). Treatment trends include linear and quadratic trends of the reformed districts/counties as a whole. "Control" refers to the selection variables that determine the assignment of reformed districts/counties in a city.