Economies of Scale or Specialization? The Impact of Vertical Unbundling on Firm Productivity in the Electricity Industry

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Abstract

Many electricity markets in the world have experienced the vertical unbundling where the generation and transmission sectors were separated from a vertically-integrated monopolistic power company. This restructuring could positively impact the productivity of the firms due to intensified competition and enhanced autonomy but could also negatively affect the productivity due to the loss of scaled economy. By exploiting a unique feature of the vertical unbundling that took place in China in 2003 that some independent electricity companies remained vertically-integrated after the restructuring, this study finds that vertical unbundling decreased the productivity of the generation firms but increased the productivity of the transmission firms. Additional investigation reveals that the discrepancy of the restructuring impacts between generation and transmission sectors is related to the pre-existing conditions of the electricity industry: in the regions where the investment of the generation sector was more prioritized while the investment of the transmission sector was more suppressed before the restructuring, vertical unbundling had a more negative impact on the generation firms but a more positive impact on the transmission firms.

Keywords: vertical unbundling, electricity industry, productivity, integration

JEL classification: L22, L25, L51, Q48

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1 Introduction

Vertical integration used to be the predominant organizational form of electric utilities in which generation, transmission and distribution segments are integrated in a single firm, which acts as a vertically-integrated natural monopoly. The main rationale of vertical integration for the electricity market relates to the unique characteristics of the industry: the electricity cannot be easily stored and needs to be transmitted from generators to consumers to meet demand at all times, thus requiring coordination between the various supply stages. From the theoretical perspective, vertical integration could reduce holdup problems and enhance investments by all contracting parties (Williamson, 1975, 1985), and reduce ex ante investment inefficiencies due to ex post rent expropriation (Grossman and Hart, 1986; Hart and Moore, 1990). Some empirical evidence suggests that vertical integration leads to cost reduction through economies of scale (Kaserman and Mayo, 1991; Kwoka, 2002; Jara-Diaz et al., 2004; Fraquelli et al., 2005; Nillesen and Pollitt, 2011; Gugler et al., 2017). The cost savings from vertical integration are mainly achieved through coordination advantages such as more efficient investment planning, and sharing of information, inputs, personnel, management, and risks. Since upstream power plants need to coordinate with downstream transmission networks, the greatest vertical synergies occur between the generation and transmission segments, whose vertical integration might lead to the largest cost savings (Meyer, 2012).

In recent decades, there has been a movement towards restructuring the electricity markets across the world, which mostly consists of vertical unbundling such that an integrated power company is divided into independent transmission and generation firms. The primary purpose of the restructuring is to remove anticompetitive forces and foster the competition among generation firms in order to boost the productivity and reduce the cost of electricity production. Since the transmission grid and distribution lines feature typical network characteristics associated with a natural monopoly, the transmission sector still needs to be regulated (Gugler et al., 2017). Therefore, the generation firms may face more intensified competition after the restructuring, compared with the transmission firms that still possess monopolistic power. Because of the competition effects, some economic studies favor specialization over integration as they find specialization better improves firm efficiency and reduces costs (Fabrizio et al., 2007). On the contrary, vertical integration of various stages of production could potentially increase the degree of complexity and the difficulty of coordination, thus exposing the firm to higher risks under turbulent environments (Harrigan, 1985). In addition, since the allocation of ownership rights affect the ex ante investments, non-integration would be a more desirable arrangement if the investment decisions are equally important among the involved parties (Grossman and Hart, 1986).

Although the practice of vertical unbundling in the electricity market has been widely adopted in many economies around the globe including both developed and developing countries[1], the economics literature is far from reaching either theoretical or empirical consensus on whether vertical integration or vertical unbundling would be the preferred organizational form of the electricity industry. Since the benefits of vertical unbundling depends on the forgone benefits of vertical integration, it is not certain to what extent the benefits of the increased productivity from intensified competition and increased autonomy due to the separation would be offset by the efficiency loss due to the loss of economies of scale and coordination advantages. Moreover, the existing literature seems to have overlooked that the benefits of specialization relative to integration critically depends on the development stage of the electricity industry or the pre-existing conditions of the electricity infrastructure development before the restructuring takes place. When the industry is less developed and power shortage is still a major concern, priority might be given to investment in the generation sector during vertical integration and the investment in the transmission sector would thus be suppressed. This coincides with the Property Right Theory by Grossman and Hart (1986), which finds that vertical integration is more likely to result in one party over-investing and the other under-investing since firms with ownership use residual rights of control to obtain a large share of the ex post investment returns, and thus influence their ex ante investment levels. As a result, vertical-unbundling that occurs at the stage where the investment levels of generation and transmission sectors are unbalanced is more likely to lead to a larger discrepancy in the productivity impacts of the restructuring on the generation and transmission sectors, which also differ in terms of their market structure.

Most empirical studies that aim to compare vertical integration and specialization in the electricity market exploit the restructuring reform as a natural experiment and try to estimate its impacts on either the operating cost or productivity of the electricity firms. However, they usually face an identification challenge that constructing a valid control group to compare with the firms that experienced vertical unbundling is difficult since the restructuring usually affects the entire industry and identifying the firms that are not influenced by the policy is almost impossible. By investigating the effects of the vertical unbundling reform that took place in China in 2003, this study exploits a unique feature of the Chinese electricity market that 13 local independent

[1]The countries that experienced the vertical unbundling include UK, EU countries, Chile, Australia, New Zealand, United States, China, etc. See Newberry (2002) and Foster et al. (2017) for a detailed summary.

electricity companies that are located in 10 provinces[2] were not controlled by the State Power Company (SPC) and remained vertically-integrated during the restructuring. This group of companies serves as an ideal comparison group to the treated companies that were vertically-unbundled. Through a difference-in-difference framework, we estimate the restructuring of the Chinese electricity market in 2003 on the productivity (measured as TFP) of both the generation and transmission firms, relying on the firm-level data of the Above-scale Industrial Firms Panel of China for the years of 2000-2007.

We first present a theoretical framework to investigate the impacts of vertical unbundling on the productivity of both the generation and transmission sectors, taking into account both the pre-existing conditions of the electricity market before the restructuring and the competition intensity after vertical unbundling. Based on the theoretical motivation, we then empirically estimate the impacts of vertical unbundling on the generation sector by comparing the productivity of the generation firms previously managed by the SPC with the productivity of the generation firms that were managed by the independent enterprises, and estimate the impacts of the restructuring on the transmission sector using the same strategy. We find that the vertical unbundling decreased the productivity of the generation firms by 36.8% relative to vertically-integrated local generators, because of the loss of scaled economy and investment priority, and the rigidness in adjusting resources when facing more intensified competition. However, the restructuring increased the productivity of the transmission companies by 28.4% as they enjoyed more flexibility in making investments of transmission grids and distribution lines since the development of the transmission sector had long been subordinated before the reform. The discrepancy of the findings between the generation and transmission sectors is related to the development stage of the electricity industry when the restructuring occurred. Because of the historic power shortages and frequent blackouts, there was a tendency of the electricity industry to only focus on the investment in generation but ignore the transmission and grid investments (*FGIT*[3]), in Chinese terms - *Zhong Fa Qing Gong*, and thus the construction of power transmission and distribution grid was far from adequate. Our additional investigation reveals that in regions where the generation sector was more prioritized and the transmission sector was more suppressed before the restructuring, the generation firms suffered a larger reduction in

[2]The 10 provinces are Shanxi, Shaanxi, Sichuan, Guangxi, Chongqing, Jilin, Hunan, Yunnan, Hubei and Xinjiang, respectively.

[3]In the following text, we will use the abbreviation *FGIT*, *Focusing on the Generation and Ignoring the Transmission*, to represent the situation where the investment of the generation sector is prioritized while that of the transmission sector is subordinated.

productivity while the transmission firms experienced a larger productivity increase after vertical unbundling.

Our study contributes to the literature that investigates the 2003 restructuring of the Chinese electricity market. Du et al. (2009) use two rounds of plant-level cross-sectional data of fossil-fired generation plants in 1995 and 2004 and estimate the impact of the restructuring on the input demand of employees, fuel and nonfuel materials. They find the restructuring improved the efficiency of labor and nonfuel inputs, but there was no efficiency gain of fuel inputs. By using a non-parametric approach, Zhao and Ma (2013) study the impact of the restructuring in 2003 on the operational efficiency for a balanced panel of 34 large power plants for the period of 1997-2010. They find that the vertical unbundling boosted the productivity of China's power plants, but the impacts on the previously SPC-managed power plants and the independent power plants are insignificant. Gao and Biesebroeck (2014) study whether the vertical unbundling boosted productivity of the electricity generation firms and find that the restructuring decreased firms' labor and material use by 7 and 5 percent, respectively. Our study differs from these existing studies in several ways. First, Du et al. (2009) assigned the firms that were originally controlled by the State Power Company (SPC) as treated, and Gao and Biesebroeck (2014) identified the firms that were officially denoted as state-owned in 2002 as treated. Both of the studies included the firms that had mixed ownership and the potential subsidiaries of the state companies that might be directly impacted by the restructuring in the control group, which could confound the identification of the causal impact of the vertical unbundling. Our identification, however, relies on the comparison between the firms that formerly belonged to the SPC and thus experienced vertical unbundling and the 13 local independent firms that were not directly influenced by vertical unbundling. Second, most studies explore the impact of the restructuring on the generation sector only, while our study not only looks at the impacts on the generation firms, but also the transmission sector, which provides a more complete assessment of the vertical unbundling on the entire electricity industry. We find that the heterogenous impacts on the two segments are related to both their difference in market structure and the development stage of the electricity industry.

Our study is also related to the substantial literature that studies the impact of the restructuring of the electricity market in both developed and developing countries, including Newbery and Pollitt (1997); Borenstein et al. (2002); Bushenell and Wolfram (2005); Xu and Chen (2006); Hattori and Tsutsui (2004); Pombo and Taborda (2006); Nagayama (2007); Joskow (2008); Zhang and Parker (2008); Pittman and Zhang (2010) and Sen and Jamasb (2012).

Some studies use the restructuring of electricity market as a natural experiment to investigate specifically the impact of the competition or vertical economies on the productivity and efficiency of the electricity firms. Fabrizio et al. (2007) estimate the impact of the restructuring programs on the input demand for non-fuel operating expenses of the generation plants, and find municipally-owned plants, whose owners were mostly unaffected by restructuring had the smallest efficiency gains, while privately-owned plants in states that experienced the restructuring had the largest reduction in operating expenses and employment. Gugler et al. (2017) use firm-level data on 28 major European electricity utilities for the period 2000-2010 and study the efficiency of the vertical divestiture of generation and transmission, and they find the vertical integration between generation and transmission is associated with significant cost savings. Most of the studies either exploit a natural experiment to examine the changes of market structure on the performance of electricity generation companies or use cross-sectional variation to estimate the cost impact of vertical synergy and vertical unbundling. These studies usually focus on specific research contexts and do not analyze the market fundamentals that may affect the performance of vertical integration and specialization. Our work highlights that the productivity impacts of restructuring is related to development stage of the industry, which provides new insights to the existing literature that draws mixed conclusions in regard of the preferred organizational form of the electricity market.

In addition to the contribution to the literature, the findings of this study also have important policy implications. First, considering that China is the world's largest emitter of CO_2 and its electricity industry accounts for 48.8 percent of the total national emissions, a more thorough understanding of the impact of the vertical unbundling on the productivity of the electricity firms is critically important in terms of evaluating the environmental impacts. Second, the effectiveness of the vertical unbundling has critical implications for the electricity accessibility and wellbeing of Chinese households. We find that the vertical unbundling played a significant role in the expansion of the transmission and distribution network after 2003, especially in rural areas, which greatly improved the accessibility of electricity and living standards in rural areas, and reduced the inequality of the electricity availability among urban and rural households. Third, our finding that the effectiveness of the restructuring depends on the development stage of the electricity market provides important insights and guidance for other developing countries that plan to adopt vertical unbundling to promote the competition of electricity generation. As indicated by the Property Right Theory (Grossman and Hart, 1986), the unbalanced investments between generation and transmission sectors may arise from vertical integration, and thus will not be a unique phenomenon in China but a likely condition in most developing countries where the electricity infrastructure is less developed and the priority and more controlling power are given to the generation sector.

The paper proceeds as follows. Section 2 briefly describes the industry and policy background of the study and the data. Section 3 provides a theoretic model to distill intuition for the empirical analysis. Section 4 describes the empirical strategy. Section 5 presents the estimation results and Section 6 concludes.

2 Industry and Policy Background and Data

In this section, we first introduce the restructuring of China's electricity industry in 2003 and then present data used in the empirical analysis.

2.1 Industry Background

The electricity sector has been playing a critical role in providing the support for the rapid economic growth in China in the past decades, as the development of the manufacturing sector largely depends on a reliable supply of electricity. Before 1985, the electricity sector was vertically integrated, including generation, transmission, distribution and retailing. The Ministry of Electricity Power (MEP) and local Bureaus of Electricity Power (BEP), essentially part of the central and local governments, were in charge of the decisions of investment and management in the electricity sector, i.e. granted triple identities as regulator, investor and manager (Zhao and Ma, 2013). The operation of vertical integration and the absence of competition depressed the development of the electricity industry, resulting in nation-wide power shortages for decades.

Aimed at solving the problem of electricity shortages, the electricity industry experienced three stages of market-oriented reforms in China. This first stage was the diversified investment financing reform in electricity generation sector during the period of 1985-1996. In 1985, to relieve the shortages of generation capacity, the government deregulated the generation market, allowing investments from local governments, domestic private enterprises, and even foreign companies. However, the transmission and distribution markets were still managed by the MEP, operating as a monopoly. After the reform, the supply and demand of the electricity market was basically balanced in the 1990s, while the MEP still remained the dominant player in the industry. The second stage was the management system reform during the years of 1997-2001. To cope with the problem that the supervision authority had the incentives to protect and strengthen the monopolistic status of the electricity industry through administrative means, the MEP was dismantled in 1997, with all its electricity assets taken over by a newly established public utility, the State Power Company (SPC), while its administrative functions were transferred to the State Economic and Trade Commission (SETC). Still vertically integrated, the SPC was responsible for the operation of the entire electricity system.

The third stage was the vertical-unbundling restructuring in the years following 2002, which became the largest step of the reform in the electricity industry since 1985. To remove the monopolistic status of the SPC and introduce the competition in the generation sector, on December 29th of 2002, the State Council launched formally the restructuring that separated the generation sector from the transmission sector, which took effect in 2003. The former SPC was restructured with its generation assets reallocated to five generation companies (Big Five), and its transmission and distribution assets inherited by two transmission companies.[4] It was widely expected that the unbundling and deregulation would eventually improve the efficiency of electricity generation through specialization and increased competition.

The vertical unbundling in 2003 impacted the generation and transmission sectors differently. Before the restructuring, the investment in the generation sector was prioritized while the construction of power transmission and distribution grid was far from adequate. More specifically, the historic power shortages leaded to a tendency of the electricity sector to only focus on the investment in generation but ignore the transmission and grid investment, in Chinese terms-*Zhong Fa Qing Gong*, which resulted in the low efficiency of the transmission companies. The ratio of the electricity grid investment over the total electricity investment was 32.6% during the period of 1998-2002 in China, as shown in Appendix Figure A.1, far lower than over 50% levels in advanced economies. The unbalanced development between generation and transmission sectors severely constrained the growth of electricity industry. Moreover, the lag of grid construction resulted in a severe inequality of power supply across different regions, and frequently triggered the phenomenon that power shortages and power waste coexisted.

After the restructuring in the year of 2003, the transmission firms separated from the former SPC could avoid the interest conflicts with the generation firms and thus pay more attention to the construction of transmission and distribution grid and improve their productivity. Hence, the vertical unbundling in 2003 would have a positive impact on the efficiency of transmission companies through the specialization effects. However, the effects of the restructuring on the

[4] The five generation companies are China Huaneng Corporation, China Datang Corporation, China Huadian Corporation, China Guodian Corporation and China Power Investment Corporation, and the two transmission companies are State Grid Company and China Southern Grid Company.

generation companies are uncertain. On one hand, the generation companies dismantled from the SPC started to face more intense competition from both state-owned and private generation companies. On the other hand, they lost the former advantages of scaled economies from vertical integration. As shown in Appendix Figure A.2, the generation sector experienced a significant increase in the competitiveness after the restructuring. However, because of the natural monopolistic feature of the transmission sector which requires stable coverage, the transmission sectors are dominated by the only two national transmission companies after the restructuring, which provided service for different regions. In the empirical analysis, we will investigate the effects of the vertical unbundling on the productivity of the generation and transmission sectors, respectively.

2.2 Data Description

Our primary data source is the firm-level data of the Above-scale Industrial Firm's Panel, which is provided by China's National Bureau of Statistics (NBS). The data covers all state-owned firms and non-state-owned firms with annual sales of at least 5 million RMB. Because the data set only started to report capital stock data for electricity firms in 2000, which is needed to measure total factor productivity, we define our sample period as years between 2000 and 2007. Besides each firm's name, labor usage, ownership type, age and address, the data also provides firms' financial information, such as added value, fixed assets, capital stock, and intermediate inputs etc. In this paper, since we focus on the electricity generation and transmission firms, we select those firms that belong to codes 441 and 442 under Chinese Industrial Classification.

The vertical integration was effectively unbundled in 2003, dismantling the State Power Company and divesting its generation assets into five generation companies and its transmission and distribution assets into two transmission companies. By the end of 2010, the five generation companies accounted around half of electricity capacity in China (Zhao and Ma, 2013), though none owned more than 20% market share in any of the new power regions (Gao and Biesebroeck, 2014). The two transmission companies are the two dominant players in the electrical transmission sector, with their grids covering the most parts of China. Despite the vertical-unbundling at the national scale, there existed 13 independent local electricity enterprises, for instance Guangxi Guidong Co., Ltd, which were not directly impacted by the restructuring and still remained their vertically-integrated operation in 10 provinces. The 13 local electricity enterprises remained their organizational form for at least two main reasons. On one hand, these enterprises were generally located in the areas with abundant coal and water resources owning independent generation assets and grid systems, and thus could basically meet the electricity demand of the local users. Hence, the local governments were reluctant to allow them to be merged into the two national transmission companies formed after the restructuring. On the other hand, these local electricity enterprises were situated in the areas with weaker distributional networks and poorer connectivity across different counties, so the two national transmission companies were also unwilling to take over these enterprises. Therefore, those 13 local electricity enterprises could be served as the control group when estimating the impact of vertical unbundling because they maintained vertical integration after the restructuring. In this study, we focus on the firms in the 10 provinces where the 13 independent electricity enterprises were located, using the independent electricity firms as the control group and the generation and transmission firms originated from SPC as the treatment group, which is completely different from the sample selection and identification strategy adopted by Gao and Biesebroeck (2014).

In the electricity generation sector, we select five generation companies and their subsidiaries as the treatment group similar to Du et al. (2009) and the 13 local electricity enterprises as the control group. The five generation companies and their subsidiaries can be easily identified by their names. As for the control group, after first eliminating both the private and foreign companies that were never practiced integrated operation, we use the Celestial Eye Survey (CES)[5] to facilitate identifying the generation firms that belong to the local electricity enterprises. CES, a kind of commercial paid software, provides basic information of 180 million social entities in China, including each firm's shareholder name, ownership, scope of business, ultimate beneficiary, etc.

For the electricity transmission sector, the two transmission companies dismantled from SPC (State Grid and China Southern Grid) are identified as the treatment group, and the transmission firms that belong to the 13 independent electricity enterprises are classified as the control group. Different from the generation sector, the Chinese government did not allow any private and foreign investment in the electricity transmission sector. Again, we use the CES tool to identify the transmission firms of the 13 local electricity enterprises, and the firms that belong to the two national transmission companies. In addition, to remove the effects of the newly entered firms, which are usually more productive, we only consider the firms that were established before 2003 in both the control and treatment groups, in order to accurately estimate the impact of the vertical unbundling on firms productivity. Therefore, we end up having 133 treatment firms and 218 control firms in the generation sector, and 304 treatment firms and 208 control firms in the

[5]The official website is https://www.tianyancha.com/.

transmission sector.

In our analysis, firm performance is measured by the total factor productivity (TFP), which is estimated from firm input and output variables. A firm's TFP reflects how much output it produces from a given amount of inputs. Due to a large amount of zero investment in the sample, we employ the methodology of Levinsohn and Petrin (2003) rather than Olley and Pakes (1996) to estimate TFP. The advantage of this method is that it can address the simultaneity problem caused by unobserved productivity shocks, using intermediate inputs as proxies. In the robustness check section, several other methods are also adopted to measure TFP, such as Ordinary Least Squares, Fixed Effects and the method put forward by Ackerber et al. (2015).

Figure 1 depicts the annualized average TFP levels of electricity generation and transmission firms between 2000 and 2007, respectively. By contrast, we find that TFP of the treatment group and the control group experienced similar trend pattern before the restructuring in 2003 for the electricity generation sector. In the post-restructuring years, TFP in the control group speeded up while the treatment group decreased initially, and then rose. And the gap between the two diminished at a large margin. The transmission sector, however, witnessed a different pattern. In the pre-reform years, TFP in the treatment group bore a similar trend pattern as that of the control group. However, in the post-restructuring years, TFP of the treatment group accelerated, with a larger gap between the two groups compared to the pre-restructuring period.

Four firm attributes are included in our empirical model, including employment, age, state share, and subsidy. Employment counts the total number of employees of the firm, a measure of firm size. Age measures the number of years a company has been in operation. State share is the ratio of equity owned by state. Subsidy is a dummy variable, equaling one if the firm receives any subsidy from the state and zero otherwise, which is used to account for a firm's political connections.

Table 1 summarizes the variables above for firms in the generation and transmission sectors separately before the reform. Consistent with Figure 1, the level of TFP of the treatment firms is higher than that of the control firms in both sectors, with a bigger gap in electricity generation sector. In addition, it is apparent that there appears to be pre-existing significant differences between the treatment group and the control group for employment and state share in the generation sector, and for age in the transmission sector. We will control for these underlying differences in firm attributes in the empirical analysis.

3 Theoretical Framework

To motivate our empirical analysis, this section provides a theoretic model to illustrate the impact of vertical unbundling on firm's productivity for both the generation and transmission sectors. We assume that firms maximize profits by choosing R&D investment levels to improve technology. Consider a static model of producing one good, i.e. the electricity. Denote the quantity demanded of the good as Y. We assume a representative consumer, with an income level E, gains utility of $\log(Y)$ when consuming Y units of electricity. Therefore, if the price of electricity is P, $Y = E/P$ is the demand for electricity. Assume that the electricity industry consists of both generation and transmission sectors. We examine the technology levels for both generation and transmission sectors during vertical integration and vertical unbundling, respectively.

3.1 The Vertical Integration Period

Assume that the total supply of the electricity follows a CES form

$$Y = \left(\sum_{i=1}^{N} y(i)^{\rho} \right)^{1/\rho}$$

where $y(i)$ is the output of the representative firm, and N is the total number of electricity firms in vertical integration period that exhibit monopolistic competition. Let $\rho = 1 - \frac{1}{\sigma}$, and σ is the elasticity of substitution between any two products of the electricity firms, which is larger than 1. Suppose that the production function of the representative firm i is

$$y(i) \equiv y_G^{\theta}(i) y_T^{1-\theta}(i) = a l_G^{\theta}(i) l_T^{1-\theta}(i),$$

where $a = a_G^{\theta}(inv_G)\ a_T^{1-\theta}(inv_T)$ is the total technology that depends on R&D investment levels on generation and transmission sectors, inv_G and inv_T. $y_j(i) = a_j(inv_j) l_j(i)$ and $a_j(inv_j) = inv_j^{\frac{1}{K_j}}$, $j = \{G, T\}$, and G and T are short for generation and transmission, respectively. Due to the fact that technology of the generation sector speeds up faster than that of the transmission sector for a given R&D investment, the parameter K_T is assumed no smaller than K_G. θ measures the degree of *Focusing on the Generation and Ignoring the Transmission* ($FGIT$) in vertical integration period, and θ is larger than 1/2 for the electricity market in China when the industry is less developed and priority is given to the investment of the generation sector. The higher θ is, a more serious $FGIT$ the market experiences. The total revenue of the firm is

$$r(i) \equiv p(i)y(i) = \left(\frac{P(i)}{P}\right)^{1-\sigma} E,$$

where $p(i){=}\frac{1}{\rho}\left(\frac{w_G}{\theta}\right)^{\theta}\left(\frac{w_T}{1-\theta}\right)^{1-\theta}\frac{1}{a}$. Hence,

$$r(i){=}a^{\sigma-1}\left(\frac{w_G}{\theta}\right)^{(1-\sigma)\theta}\left(\frac{w_T}{1-\theta}\right)^{(1-\sigma)(1-\theta)}(\rho P)^{(\sigma-1)}E.$$

The firm's profit, considering both fixed costs and R&D investment costs to improve technology, is the equal to

$$\pi(i) = \frac{r(i)}{\sigma} - inv_G - inv_T - f_G - f_T = \frac{A}{\sigma} inv_G{}^{\frac{(\sigma-1)\theta}{K_G}} inv_T{}^{\frac{(\sigma-1)(1-\theta)}{K_T}} - inv_G - inv_T - f_G - f_T,$$

where $A{=}\left(\frac{w_G}{\theta}\right)^{(1-\sigma)\theta}\left(\frac{w_T}{1-\theta}\right)^{(1-\sigma)(1-\theta)}(\rho P)^{(\sigma-1)}E$, and $\frac{r(i)}{\sigma}$ is the net revenue after deducting the labor cost. w_G is the wage of labor in the generation sector, and w_T is that in the transmission sector. The firm chooses the R&D investment for both the generation and transmission sectors to maximize the profit. The firm's objective is to maximize the profit, namely

$$\max_{inv_G, inv_T} \ \pi(i) = \frac{A}{\sigma} inv_G{}^{\frac{(\sigma-1)\theta}{K_G}} inv_T{}^{\frac{(\sigma-1)(1-\theta)}{K_T}} - inv_G - inv_T - f_G - f_T,$$

where f_G and f_T are the fixed costs in the generation and transmission sectors, respectively. Considering that the fixed cost of the former far exceeds that of the latter in reality, there is $f_G << f_T$. The optimal choices of inv_G and inv_T are respectively given by

$$inv_G^{VI}{=}\frac{(\sigma-1)\theta}{K_G}\frac{r(i)}{\sigma},$$

$$inv_T^{VI}{=}\frac{(\sigma-1)(1-\theta)}{K_T}\frac{r(i)}{\sigma}.$$

To ensure that the profit is zero, it implies that

$$\begin{aligned} f_G{+}f_T &{=}\left(1{-}\left(\frac{\theta}{K_G}+\frac{1-\theta}{K_T}\right)(\sigma-1)\right)\frac{r(i)}{\sigma} \\ &= \left(1{-}\left(\frac{\theta}{K_G}+\frac{1-\theta}{K_T}\right)(\sigma-1)\right)\frac{E}{\sigma N^{VI}} \end{aligned},$$

and hence

$$inv_G^{VI}{=}\frac{(\sigma-1)\theta(f_G+f_T)}{K_G}\left(1{-}\left(\frac{\theta}{K_G}+\frac{1-\theta}{K_T}\right)(\sigma-1)\right)^{-1}, \tag{1}$$

$$inv_T^{VI}=\frac{(\sigma-1)(1-\theta)(f_G+f_T)}{K_T}\left(1-\left(\frac{\theta}{K_G}+\frac{1-\theta}{K_T}\right)(\sigma-1)\right)^{-1}. \tag{2}$$

The equilibrium number of firms during the period of vertical integration is

$$N^{VI}=\left(1-\left(\frac{\theta}{K_G}+\frac{1-\theta}{K_T}\right)(\sigma-1)\right)\frac{E}{\sigma(f_G+f_T)}. \tag{3}$$

To ensure a positive R&D investment, with $K_T \geq K_G$, there is $K_T \geq K_G > \sigma - 1 > 0$.

3.2 The Vertical Unbundling Period

3.2.1 The Transmission Sector

During the period of vertical unbundling, transmission firms purchase electricity from generation firms as an intermediate product and both sectors maximize their own profits separately. Assume that the total electricity supply in the transmission sector is

$$Y_T = \left(\sum_{i=1}^{N_T} y_T(i)^{\rho}\right)^{1/\rho}$$

where $y_T(i)$ is the output of a representative transmission firm, and N_T is the number of transmission firms during the vertical unbundling period. The production function of the firm in the transmission sector is

$$y_T(i) = a_T(inv_T)m_G^{\alpha}(i)l_T^{1-\alpha}(i),$$

where $m_G(i)$ denotes the intermediate input, which is purchased from the generation sector, and α is the revenue share distributed to the intermediate input. The total revenue of the transmission firm is

$$r_T(i)=A_T {a_T}^{\sigma-1}(inv_T),$$

where $A_T = \left(\frac{P_G}{\alpha}\right)^{(1-\sigma)\alpha}\left(\frac{w_T}{1-\alpha}\right)^{(1-\sigma)(1-\alpha)}(\rho P)^{(\sigma-1)}E$, P_G denotes the price of the intermediate product from the generation sector. Therefore, the transmission firm solves the following problem

$$\max_{inv_T} \ \pi_T(i) = \frac{A_T}{\sigma}{inv_T}^{\frac{\sigma-1}{K_T}} - inv_T - f_T.$$

The optimal choice of inv_T is then

$$inv_T^S=\frac{(\sigma-1)}{K_T}\frac{r(i)}{\sigma}.$$

Similarly, the fixed cost f_T that ensures the zero profit is

$$f_T= \left(1-\frac{\sigma-1}{K_T}\right)\frac{r_T(i)}{\sigma} = \left(1-\frac{\sigma-1}{K_T}\right)\frac{E}{\sigma N_T},$$

and hence

$$inv_T^S=\frac{(\sigma-1)f_T}{K_T}\left(1-\frac{\sigma-1}{K_T}\right)^{-1}. \tag{4}$$

The number of the transmission firms in equilibrium is

$$N_T^S= \left(1-\frac{\sigma-1}{K_T}\right)\frac{E}{\sigma f_T}. \tag{5}$$

3.2.2 The Generation Sector

Assume the total power supply in the generation sector is

$$Y_G = \left(\sum_{i=1}^{N_G} y_G(i)^{\rho'}\right)^{1/\rho'}$$

where $y_G(i)$ is the quantity supplied of the representative generation firm, and N_G is the number of generation firms during vertical unbundling. $\rho'= 1-\frac{1}{\sigma'}$, and σ' is the elasticity of substitution between any two products of the generation firms, which is larger than σ during vertical integration because of more intensified competition due to a lower entry barrier of the generation firms. The production function of the generation firm is

$$y_G(i) = a_G(inv_T)l_T(i).$$

Similarly, the total revenue of the generation firm is

$$r_G(i)=A_G {a_G}^{\sigma'-1}(inv_T),$$

where $A_G = w_G^{1-\sigma'}(\rho' P_G)^{(\sigma'-1)}E_G$. E_G denotes the total demand of electricity. The intermediate input in the transmission sector is equal to the output in the generation sector, and is therefore

$$E_G= (1-\frac{1}{\sigma})\alpha E.$$

The generation firm solves the following problem

$$\max_{inv_G} \ \pi_G(i) = \frac{A_G}{\sigma'} inv_G^{\frac{\sigma'-1}{K_G}} - inv_G - f_G.$$

The optimal choice of investment for the generation firm inv_G is then

$$inv_G^S = \frac{\sigma'-1}{K_G} \frac{r_G(i)}{\sigma'}.$$

To ensure the zero profit in generation sector, there is

$$f_G = \left(1 - \frac{\sigma'-1}{K_G}\right) \frac{r_G(i)}{\sigma'} = \left(1 - \frac{\sigma'-1}{K_G}\right) \frac{E_G}{\sigma' N_G},$$

and hence

$$inv_G^S = \frac{(\sigma'-1) f_G}{K_G} \left(1 - \frac{\sigma'-1}{K_G}\right)^{-1}. \tag{6}$$

The total number of the generation firms in equilibrium is

$$N_G^S = \left(1 - \frac{\sigma'-1}{K_G}\right) (1 - \frac{1}{\sigma}) \frac{\alpha E}{\sigma' f_G}. \tag{7}$$

Corollary 1: Suppose that $f_G << f_T$, $K_T \geq K_G > \sigma' - 1 > \sigma - 1 > 0$ and $\alpha \geq \bar{\alpha}$. Compared with the period of vertical integration, the generation sector has a lower technology, but more firms in the period of vertical unbundling. This technology reduction will be exaggerated by a more series *FGIT* (a higher θ), but will be mitigated by a more intensified competition (a higher σ).

Proof of Corollary 1. Since the generation firm's technology improves due to a higher R&D investment, i.e. $a_G(inv_G) = inv_G^{\frac{1}{K_G}}$, the comparison of the firm's technology between the two periods is equivalent to comparing the relative size of the corresponding R&D investments. As shown in equation 1, the optimal R&D investment of the generation firm during the vertical integration period is

$$inv_G^{VI}(i) = \frac{(\sigma-1)\theta(f_G + f_T)}{K_G} \left(1 - \left(\frac{\theta}{K_G} + \frac{1-\theta}{K_T}\right)(\sigma - 1)\right)^{-1},$$

while that during the unbundling period is

$$inv_G^S(i) = \frac{(\sigma'-1) f_G}{K_G} \left(1 - \frac{\sigma'-1}{K_G}\right)^{-1}.$$

Hence, the relative investments between the two periods is

$$\frac{inv_G^S(i)}{inv_G^{VI}(i)} = \frac{(\sigma'-1)f_G}{(\sigma-1)\theta(f_G+f_T)}\left(1-\left(\frac{\theta}{K_G}+\frac{1-\theta}{K_T}\right)(\sigma-1)\right)\left(1-\frac{\sigma'-1}{K_G}\right)^{-1},$$

which is smaller than 1 if $f_G << f_T$ and $K_T \geq K_G > \sigma' - 1 > \sigma - 1 > 0$. This implies that the technology of the generation firm during the vertical unbundling period is lower than the vertical integration period.

As the parameter σ' increases, the ratio $\frac{inv_G^S(i)}{inv_G^{VI}(i)}$ becomes larger, which states clearly that more intensified competition could promote the generation firm's technology. But the ratio becomes smaller as θ is larger, which implies that a more serious $FGIT$ during vertical integration leads to a larger decline in the generation firm's technology when the generation and transmission sectors are separated.

During the vertical integration period, the number of generation firms in equilibrium is

$$N_G^{VI} = N^{VI}=\left(1-\left(\frac{\theta}{K_G}+\frac{1-\theta}{K_T}\right)(\sigma-1)\right)\frac{E}{\sigma(f_G+f_T)},$$

while during the period of vertical unbundling it is

$$N_G^S=\left(1-\frac{\sigma'-1}{K_G}\right)(1-\frac{1}{\sigma})\frac{\alpha E}{\sigma' f_G}.$$

Hence, the ratio

$$\frac{N_G^S}{N_G^{VI}}=\frac{\alpha\sigma(f_G+f_T)}{\sigma' f_G}\left(1-\left(\frac{\theta}{K_G}+\frac{1-\theta}{K_T}\right)(\sigma-1)\right)^{-1}\left(1-\frac{\sigma'-1}{K_G}\right)(1-\frac{1}{\sigma}),$$

which is much larger than 1 in the case of $f_G << f_T$,$K_T \geq K_G > \sigma' - 1 > \sigma - 1 > 0$ and $\alpha \geq \bar{\alpha}$. It indicates that the number of generation firms during vertical unbundling is much more than that in the vertical integration period.

Corollary 2: Suppose that $f_G << f_T$, $K_T \geq K_G > \sigma - 1 > 0$, and $\theta > 1/2$. Compared with the vertical integration period, the transmission sector improves its technology, and increases its number of firms to a small extent during the vertical unbundling period. A more serious $FGIT$ during vertical integration will lead to a larger technology improvement of the transmission sector when the generation and transmission sectors are separated.

Proof of Corollary 2. Similar to the generation sector, the comparison of the transmission sector's technology between the two periods is equivalent to comparing their R&D investment levels. As shown in equation 2, the optimal R&D investment of vertical integration period is

$$inv_T^{VI}(i) = \frac{(\sigma-1)(1-\theta)(f_G+f_T)}{K_T}\left(1-\left(\frac{\theta}{K_G}+\frac{1-\theta}{K_T}\right)(\sigma-1)\right)^{-1},$$

while that of the unbundling period is

$$inv_T^S = \frac{(\sigma-1)f_T}{K_T}\left(1-\frac{\sigma-1}{K_T}\right)^{-1}.$$

Therefore, the ratio of the two investment levels is

$$\frac{inv_T^S(i)}{inv_T^{VI}(i)} = \frac{f_T}{(1-\theta)(f_G+f_T)}\left(1-\left(\frac{\theta}{K_G}+\frac{1-\theta}{K_T}\right)(\sigma-1)\right)\left(1-\frac{\sigma-1}{K_T}\right)^{-1},$$

which is larger than 1 if $f_G << f_T$, $K_T \geq K_G > \sigma - 1 > 0$ and $\theta > 1/2$. It indicates that technology of the transmission firm in specialization period is higher than that during the vertical integration period.

As the parameter θ increases, the ratio $\frac{inv_T^S(i)}{inv_T^{VI}(i)}$ becomes higher, indicating that the technology improvement of the transmission sector during the unbundling period is larger with a more serious $FGIT$ during vertical integration.
During the vertical integration period, the equilibrium number of the transmission firms is

$$N_T^{VI} \equiv N^{VI} = \left(1-\left(\frac{\theta}{K_G}+\frac{1-\theta}{K_T}\right)(\sigma-1)\right)\frac{E}{\sigma(f_G+f_T)},$$

while that of the unbundling period is

$$N_T^S = \left(1-\frac{\sigma-1}{K_T}\right)\frac{E}{\sigma f_T}.$$

Hence, the ratio of the number of firms during the two periods

$$\frac{N_T^S}{N_T^{VI}} = \frac{f_G+f_T}{f_T}\left(1-\left(\frac{\theta}{K_G}+\frac{1-\theta}{K_T}\right)(\sigma-1)\right)^{-1}\left(1-\frac{\sigma-1}{K_T}\right),$$

which is slightly larger than 1 with $f_G << f_T$ and $K_T \geq K_G > \sigma - 1 > 0$. It indicates that the equilibrium number of firms in the transmission sector increases slightly after the two sectors are separated during vertical unbundling.

4 Empirical Framework

Based on the intuition provided by the above theoretical analysis, we exploit the natural experiment of the 2003 restructuring of China's electricity market to investigate the impact of vertical unbundling on firms' productivity and conduct our empirical analysis in a difference-in-differences (DID) framework. We compare the changes in productivity before and after the restructuring in 2003 of the electricity firms that were directly impacted by the restructuring with those of the independent local firms that did not experience vertical unbundling. In order to comprehensively investigate the effects of the vertical unbundling on the entire electricity industry, we divide the electricity firms into two classifications, the electricity generation and transmission sectors, and estimate the effects of the restructuring on these two sectors separately. We basically estimate the performance increase or decrease of the vertically-unbundled firms, compared with the firms that remained vertically-integrated after the restructuring. Our identification strategy is mainly based on the following DID model:

$$TFP_{it} = \beta(Unb_i \times Post03_t) + \alpha_i + \gamma X_{it} + \phi_t + \varepsilon_{it} \tag{8}$$

where TFP_{it} is total factor productivity of firm i in year t, which measures firm productivity. $Post03_t$ is a dummy variable equaling one for the years 2003 and onward, and zero for the years before 2003 since 2003 is the first year that vertical unbundling was officially implemented. Unb_i is an indicator variable equaling one if firm is classified into the treatment group and experienced the vertical unbundling, and zero for the firms who remained vertically integrated. During the restructuring that started in the year of 2003, there existed 13 independent local electricity enterprises, which were not controlled by the SPC and were not directly impacted by the restructuring. The generation and transmission firms that belonged to the 13 independent enterprises are therefore used as the control group, and all the other firms that belonged to the SPC and were unbundled are considered as the treatment group. β is the coefficient of interest, which is the estimate of the interaction between the vertical unbundling dummy and $post03$ dummy. This coefficient measures the additional technology improvement or decrease of the electricity firms that experienced vertical unbundling relative to the firms that were still vertically integrated after the restructuring. As illustrated in the theoretical section, due to the existence of $FGIT$ and the difference in market structure, we would expect the coefficient to be positive for the transmission sector while being negative for the generation sector. α_i represents firm fixed effects, which controls for time-invariant firm-level differences that affect firm performance, such as the city where the firm is located. Due to the inclusion of firm-fixed effects, we only include the firms that appeared both before and after the reform in the sample. This alleviates the concern that the estimated treatment impact might be influenced by firm entry and exit. X_{it} is a vector of time-varying firm attributes that affect firm performance, including employment, age, state share and subsidy, which vary across both firms and years. ϕ_t is a set of year indicator variables to control for national-level annual trends in the electricity industry that affect firm performance uniformly, such as changes in input prices and national policies, and industry-level technological improvement. To take account of the heterogeneous impact of the industry shocks, we also include power-type-specific year dummy variables and province-specific year dummy variables to allow for differential time trends based on the power type of the generation companies[6] and the province where the firms are located.

In order to study the dynamic responses of the firm's TFP to the 2003 restructuring, we run the following regression specification:

$$TFP_{it} = \sum_{j=2000, j \neq 2002}^{2007} \beta_j \times Unb_i \times Year_j + \alpha_i + \gamma X_{it} + \phi_t + \varepsilon_{it} \quad (9)$$

where all variables are defined as before except for $Year_j$, which is a dummy variable for each year between 2000 and 2007, excluding 2002, which serves as the baseline reference. The dynamic effects are reflected by the coefficients β_j, which allow us to investigate the changes of productivity of the vertically-unbundled firms relative to the vertically-integrated firms, for each of the years surrounding the 2003 restructuring. The pre-2003 trends indicate whether there existed a pre-existing trend of firm productivity for the unbundled firms relative to the integrated firms, and the absence of a pre-existing trend could boost the confidence that the changes of productivity relative to the control group after 2003 restructuring is mainly due to the treatment of vertical unbundling.

5 Estimation Results

In this section, we first use Equation 8 to estimate the effects of the vertical unbundling in 2003 on firms' productivity, and then investigate the dynamic impacts of the restructuring using Equation 9. We estimate the effects of vertical unbundling on the electricity generation and transmission sectors respectively.

[6]The power type of the generation sector includes fossil-fueled, thermal and other power types.

5.1 Electricity Generation Sector

Table 2 reports the estimated results of the effect of the restructuring on the productivity of the electricity generation firms and transmission firms using Equation 8. Column (1) of Table 2 controls for firm and year fixed effects. The coefficient of the $Unb \times Post03$ term is negative and statistically significant at the 1% level, implying a relative productivity loss for the five generation companies. Column (2) further adds the firm attributes which vary across years; column (3) adds the interaction terms of province dummy variables and year indicators in order to control for annual trend in the electricity industry at the provincial level; column (4) finally adds the interaction terms of power type dummy variables and year indicators. The power type of the generation sector includes fossil-fueled, thermal and other power types. In all specifications, the magnitude and significance level of the $Unb \times Post03$ coefficient are basically the same. Including these additional control variables had little effect on the main results. Column (4) is our preferred specification, which finds a coefficient of -0.368, indicating that the switch of the organizational form from vertical integration to specialization lowered the productivity of five generation companies relative to 13 local electricity enterprises, narrowing the gap of productivity between the two groups by 20.9 percentage points in contrast to the gap in 2002. In all specifications, we consistently find a negative coefficient of $Unb \times Post03$, suggesting that the vertical unbundling has a negative impact on the productivity of the generation firms separated from SPC, relative to the independent electricity firms that still maintained the vertical integration. We will discuss the potential mechanisms in detail in the later section.

Equation 9 is estimated to investigate the dynamic impacts. Panel (a) of Figure 2 plots the coefficients and the 95% confidence intervals of the interaction terms between the year dummies and the Unb variable that indicates whether the firm belongs to the five generation companies that were separated from SPC. For 2000-2002, the point estimates are not statistically different from zero, revealing that the average TFP of five Companies and the 13 independent electricity enterprises grew at almost the same speed before the electricity reform took place. Because the restructuring may take a while to process, our results show that the reform effect on the productivity does not materialize immediately in 2003, which is consistent with the results from Bergh (1997). For 2004-2007, the point estimates are significantly negative, indicating that TFP of five generation companies declined relative to that of 13 independent electricity enterprises after vertical unbundling. The gradually decreasing estimates of -0.302 for 2004, -0.354 for 2005, -0.601 for 2006, and -0.524 for 2007 imply that the most divergence occurred in the year of 2006. All point estimates are also economically significant: the difference-in-difference estimate for

2006 corresponds to narrowing the average gap of TFP between the two groups by 34.2 percent in 2002.

5.2 Electricity Transmission Sector

Unlike the generation side, the transmission sector features typical network characteristics associated with a natural monopoly and its investment had long been subordinated, which may make the productivity effect of the 2003 restructuring different from that on the generation sector. Table 2 reports the regression results of Equation 8 for the transmission sector. Column (5) presents results only including firm and year fixed effects, while column (6) adds the firm covariates. Column (7) further adds the interaction terms between province dummies and year indicators, which serves as our preferred specification. Across all columns, we consistently find a positive and statistically significant coefficient for the variable of interest, $Unb \times Post03$. The magnitude of the estimated restructuring impact is equal to 0.284 as in Column (7), suggesting that the vertical unbundling increases TFP of the two transmission companies relative to the transmission firms belonging to the 13 local electricity enterprises. The restructuring makes the gap of TFP between the two groups widened by 39.2 percentage points in contrast to that in the year of 2002. The positive impact of the restructuring on the transmission sector is mainly achieved through the benefits from specialization and management autonomy. During the vertical integration, the generation side was prioritized, which impeded the development and investment of the transmission grid. Therefore, the vertical unbundling allows the transmission companies to solely focus on expanding the transmission grid and distribution lines, which largely increases their productivity. This productivity increase played a significant role in the expansion of the transmission and distribution network of China's electricity industry after 2003, especially in rural areas. Therefore, the 2003 restructuring helped improving the electricity availability in rural areas and reducing the inequality between rural and urban households in terms of electricity accessibility.

Similar to the electricity generation sector, we estimate how TFP of the electricity transmission firm responds to the restructuring dynamically using Equation 9. As shown in Panel (b) of Figure 2, the estimated coefficients of the key interactions between Unb and the year dummy variables are small and not statistically significant for the years of 2000-2002 suggesting that TFP of the two transmission companies and 13 electricity independent enterprises evolved similarly before the electricity reform. Same as in the generation sector, the reform did not have an intermediate impact in 2003, but the TFP of two transmission companies witnessed a significant increase relative to independent companies in the following years. Specifically, the difference-in-difference estimate for 2004 corresponds to 7.2 percent of the average TFP level of two transmission companies in 2002. The average economic magnitude of the $Unb \times Post03$ term decreases gradually starting 2004. However, over the period of 2004-2007, the impacts of the restructuring on the productivity of vertically-unbundled transmission firms are significantly positive relative to the vertically-integrated firms.

Combining the results from the electricity generation and transmission sectors, the vertical unbundling reduces the productivity of the vertically-unbundled generation firms, but improves the productivity of the unbundled transmission firms. The disparity of the impact of vertical unbundling between the two sides could be largely explained by the fact that the State Power Company prioritized the development of the generation side but subordinated the transmission sector during vertical integration. Additional evidence and argument in supporting of our findings will be provided in the following section.

5.3 Robustness Checks

To boost the confidence in the validity of our empirical design, we conduct a variety of robustness checks and we do these for the generation sector and transmission sector, respectively.

5.3.1 Electricity Generation Sector

Some might be concerned that the changes of the firm's productivity may occur due to other policies that were introduced before the restructuring in 2003 or other omitted variables that correlated with the restructuring. To address this concern, the placebo test is conducted, following the common practice in the literature. We assume that the vertical unbundling had occurred in 2001 instead of 2003 but the control and treatment groups are still defined in the same way as in our main specification, and we try to test if there were any significant impact of this hypothetical restructuring on the treated firms, by focusing on the observations between 2000 and 2002.

Column (2) of Table 3 manifests that the impact of the "false" restructuring in the year of 2001 was statistically insignificant at the 10% level, indicating that there were no significant differential trends between the two groups in the pre-reform period. We then conduct an alternative placebo test method, similar to Cantino et al. (2017). We make our statistical inferences by comparing the actual treatment effect to the placebo treatment effects estimated from randomly assigning the firms to the treatment group. Panel (a) of Figure 3 plots the distribution of the 5000 estimated placebo treatment effects, and also marks the actual treatment effect with the vertical line. As shown in the figure, the actual estimate is located outside of the entire distribution of the placebo estimates, supporting our argument that the effect of the vertical unbundling on the electricity generation firm's TFP is not caused by unobserved factors.

In our main specifications, all the firms included in our sample were established before the 2003 restructuring. But our sample still covers the firms which did not exist during the entire sample period, which is from 2000 to 2007. Firms' entry and exit may affect the estimate of the average treatment effect. Hence, to cope with this problem, we conduct an additional robustness check using a balanced panel that only included the firms that existed in every year over the entire sample period. Column (3) of Table 3 reports the estimated effect of the restructuring using the balanced panel, which is close to our benchmark specification.

The measurement of the firm's TFP could also impact our estimate of restructuring effects. We also try a set of robustness checks by employing different methods of calculating TFP: Ordinary Least Squares, Fixed Effects and ACF method put forward by Ackerber et al. (2015). Columns (2) to (4) of Table 4 report the estimated effects using alternative TFP measurements and all the estimates are similar to those in the benchmark specification.

5.3.2 Electricity Transmission Sector

Similar to the electricity generation sector, the effect of the restructuring may be confronted with some identification concerns. We conduct several robustness tests to investigate the sensitivity of estimates to various assumptions, which are reported in Table 3 and 4.

To rule out the concern that the estimated restructuring impact might be driven by other policies that took place before 2003 or biased by unobserved shocks that correlated with the restructuring, we adopt the two types of placebo tests, as what we did for the generation firms. The first test is to assume that the time of vertical unbundling occurred in 2001 and restrict the sample period to 2000-2002. The false difference-in-difference estimate, reported in the column (5) of Table 3, is statistically insignificant at the 10% level. We then conduct a second test where firms in the transmission sector are randomly assigned to the treatment group with the premise that the number of firms in the treatment group equals to the actual number of the treated firms. Panel (b) of Figure 3 shows that the line of the actual estimate lies in the right tail of the distribution of the placebo treatment effects, which supports our argument of estimating the treatment effects of the restructuring.

To alleviate the impact from firm's entry and exit, we conduct a robustness check by only focusing on a subgroup of firms that remained active throughout the years of 2000-2007. As shown in Column (6) of Table 3, the estimated coefficient of the $Unb \times Post03$ interaction term remains the analogous magnitude and significance level compared to that in column (4) of Table 3.

In order to check whether our estimates are sensitive to the choice of the TFP measurements, we conduct a final robustness check by estimating the effects of vertical unbundling using alternative ways of calculating TFP, same as in the electricity generation sector. The results from columns (6) to (8) of Table 4 indicate that our estimates are robust to different measurements of firms' productivity.

5.4 Mechanisms

Before the 2003 restructuring, there was a severe imbalance of investment between the electricity generation and transmission sectors in China, with the development of the generation sector being prioritized. During the period of vertical integration, the generation firms enjoyed the privileges of more resources being granted while the development of transmission firms have been subordinated. The restructuring in 2003, however, made both the generation and transmission companies independent entities, and removed the advantages that the generation firms had enjoyed due to the scaled economy from vertical integration. Thus, in the regions where the generation sector has been more prioritized, the generation firms that belonged to the Big Five would suffer more from the vertical unbundling.

To test the hypothesis, we define the variable $FGIT$, which is the average ratio of total capital stock in the generation sector over total capital stock in the entire electricity industry of a specific county in the 2000 to capture the intensity of pre-reform $FGIT$ for each county. We then run separate regressions for the subgroups of firms that are located in regions whose $FGIT$ is below and above the median level, respectively. As shown in Table 5, our results imply that in regions where the $FGIT$ was more severe before the restructuring (i.e., the investment of the generation sector was more prioritized), the vertical unbundling had a significantly negative impact on the productivity of the generation firms during the post-reform period, while no significant impact was found on that generation firms that are located in regions where $FGIT$ level is below the median.

Historically, the counties have suffered the $FGIT$ more than urban areas. To meet the needs of the increasing demand for electricity in the cities, the generation firms in the counties often needed to produce electricity to make up the shortage in the cities. Therefore, the transmission lines and distribution facilities were especially underdeveloped and poorly covered in the counties. As an alternative, we run two separate regressions for the generation firms that are located in counties and cities, respectively, and we find that the generation firms in counties suffered a significant productivity loss due to the vertical unbundling, while the restructuring did not significantly impact the generation firms in cities.

We find that the 2003 restructuring decreased the productivity of the generation firms that were vertically unbundled relative to those remained vertically-integrated. We believe that both the rigidity of adjusting labor and capital and the lack of motivation to improve efficiency lead to the decreases of the productivity of the firms that used to belong to the SPC. During the 2003 restructuring, the SPCs generation assets were divested into five generation companies that had no more than 20% market share in any of the new power-regions, the generation firms therefore faced more intense and direct competition. As the government stopped in guiding coal prices and wanted to develop a coal market, coal prices also rose significantly, concurrently with the restructuring in the electricity industry. However, state-owned generators often continued to have access to subsidized coal prices, while the independent and private generators needed to increase their efficiency in order to reduce their costs (Gao and Biesebroeck, 2014). In dealing with more intensified competition and rising coal prices, firms have stronger incentives to improve their productivity either through adopting more technology or better managing their human and capital resources. Nevertheless, central state-owned companies usually have a more rigid personnel system and have better access to government subsidies, and therefore are less incentivized to flexibly adjust their resources when facing a more intensified competition, compared with independent local generation firms. Gao and Biesebroeck (2014) find that the firms that belong to the Big Five generation companies did not decrease their employment during the 2003 restructuring. During the years of 2003-2007, China's economy, especially the manufacturing industry witnessed a rapid development due to the joining of the WTO, boosting the demand for electricity. In order to expand the electricity coverage, the transmission firms were more inclined to purchase the electricity from the generation firms that used to belong to the SPC because of the longer-term historic relationship and more established connection. Thus, the generation firms that belong to the Big Five would face a lower competition pressure and less motivated to increase their productivity, compared with other generation firms.

As for the transmission sector, since it was put into a less important position before, the transmission firms in more $FGIT$ regions are expected to experience an increase in the productivity with a larger magnitude because they could allocate more resources independently to develop the transmission lines without investment suppression from the generation side after vertical unbundling. The results in Columns (2) to (5) of Table 6 confirm this conjecture. The transmission firms located in regions where the *FGIT* was more severe experienced a larger increase in productivity than those located in regions whose *FGIT* is below the median. Alternatively, the vertical unbundling had a larger impact on the productivity of the transmission firms located in counties where the investment of the transmission sector was more suppressed, compared to the transmission firms in urban areas.

6 Conclusions

This paper investigates the impact of the vertical-unbundling in 2003 on the productivity of both the electricity generation and transmission sectors in China. We find that the vertical unbundling increased the productivity of the transmission firms that were directly impacted by the restructuring, relative to the firms that remained vertically integrated. The positive impact is larger in the regions where the development of the generation sector was more prioritized before the restructuring. The increased productivity of the transmission firms after the reform led to the expansion of transmission and distribution network in China, which reduced the inequality between rural and urban households in terms of electricity accessibility. However, the 2003 restructuring lowered the productivity of the generation firms that were separated from the SPC, relative to the independent local firms that did not experience vertical unbundling, due to the lost advantages from vertical integration. The intensified competition in the generation sector was not able to offset the negative impact of vertical unbundling on the generation firms, because of the rigidity of the human resource system and the better access to government subsidies of the state-owned firms. Our results show that the heterogenous impacts of the restructuring on the generation and transmission sectors are closely related to the development stage of the electricity market in China. Our study provides new evidence to the comparison of the performance between vertical integration and specialization operations in industries with market power, and provides valuable insights to other developing countries that plan to adopt vertical unbundling in the electricity industry where investments on generation and transmission sectors are unbalanced.

Table 1: Summary Statistics, 2002

Variable	Unbundled Firms	Integrated Firms	Difference in Means	Ratio of Means	p-value
Panel A: Generation Sector					
Ln(TFP)	8.498	5.797	2.701	1.466	0.000
	(1.148)	(1.468)			
Labor	790.797	344.855	445.942	2.293	0.000
	(662.177)	(571.027)			
Age	22.623	19.77	2.853	1.144	0.181
	(15.246)	(14.393)			
SOE	0.513	0.803	(0.291)	0.639	0.000
	(0.489)	(0.364)			
Subsidy	0.043	0.066	(0.022)	0.652	0.516
	(0.205)	(0.249)			
Observations	69	152			
Panel B: Transmission Sector					
Ln(TFP)	6.502	6.174	0.327	1.053	0.003
	(1.133)	(1.079)			
Labor	611.807	517.69	94.117	1.182	0.365
	(1261.45)	(621.407)			
Age	28.399	24.224	4.175	1.172	0.013
	(17.981)	(14.799)			
SOE	0.863	0.902	-0.039	0.957	0.178
	(0.31)	(0.239)			
Subsidy	0.067	0.063	0.004	1.063	0.871
	(0.251)	(0.244)			
Observations	238	174			

Notes: The table reports the means and standard deviations (in parentheses) of firm characteristics in 2002 for the vertically-unbundled and vertically-integrated firms, respectively. Firm TFP is measured by the Levinsohn and Petrin (2003) approach. Labor measures the total number of employees of each firm. SOE is the ratio of the state-owned investments for each firm. Subsidy is a dummy variable indicating whether the firm received any subsidy from the state.

Table 2: The Impact of Vertical Unbundling on Firm Productivity

Variable	Generation Sector				Transmission Sector		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Ln(TFP)	Ln(TFP)	Ln(TFP)	Ln(TFP)	Ln(TFP)	Ln(TFP)	Ln(TFP)
Unb×Post03	-0.304***	-0.311***	-0.305**	-0.368***	0.163***	0.185***	0.284***
	(0.108)	(0.104)	(0.132)	(0.123)	(0.059)	(0.061)	(0.063)
Ln(Labor)		0.191	0.178*	0.161*		0.062	0.062
		(0.123)	(0.105)	(0.097)		(0.078)	(0.074)
SOE		-0.083	-0.103	-0.104		-0.009	-0.013
		(0.064)	(0.065)	(0.064)		(0.047)	(0.052)
Age		0.001	0.002	0.001		0.002	0.001
		(0.002)	(0.002)	(0.002)		(0.002)	(0.002)
Subsidy		-0.04	-0.022	-0.062		-0.006	-0.005
		(0.073)	(0.072)	(0.073)		(0.048)	(0.047)
Fixed Effects							
Province-Year	No	No	Yes	Yes	No	No	Yes
Power Type-Year	No	No	No	Yes	N.A.	N.A.	N.A.
Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,669	1,572	1,572	1,572	2,741	2,593	2,593
R^2_Adj	0.92	0.922	0.924	0.927	0.834	0.823	0.828

Notes: The time period is 2000-2007. The dependent variable is natural logarithm of firm TEP measured by the Levionsohn and Petrin (2003) approach. In generation sector, Unb is an indicator variable that equals zero for firms belonging to 13 local electricity enterprises and one for firms affiliated with five generation companies that were separated from SPC, and in transmission sector it is equal to zero for firms belonging to 13 local electricity enterprises and one for firms affiliated with two transmission companies that were separated from SPC. Post03 equals zero for 2000-2002 and one for 2003-2007. Ln(labor) is the natural logarithm of the total number of employees in each firm. SOE is the ratio of the state-owned investments for each firm. Subsidy is a dummy variable indicating whether the firm receives any subsidy from the state. Standard Errors are clustered at the level of the firm and reported in parentheses. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels respectively. R^2_Adj refers to adjusted R^2 which considers the observations and the number of independent variables.

Table 3: Robustness Checks of Sample Selection

	Generation Sector			Transmission Sector		
	(1)	(2)	(3)	(4)	(5)	(6)
	Baseline	2000-2002	Balanced	Baseline	2000-2002	Balanced
	Ln(TFP)	Ln(TFP)	Ln(TFP)	Ln(TFP)	Ln(TFP)	Ln(TFP)
Unb×Post03	-0.368***		-0.352**	0.284***		0.365***
	(0.123)		(0.165)	(0.063)		(0.084)
Unb×Post01		-0.028			0.021	
		(0.17)			(0.072)	
Ln(Labor)	0.161*	-0.094*	0.083	0.062	-0.037	0.101
	(0.097)	(0.049)	(0.125)	(0.082)	(0.148)	(0.113)
SOE	-0.104	-0.251*	-0.025	-0.013	-0.305**	0.011
	(0.064)	(0.146)	(0.101)	(0.057)	(0.155)	(0.077)
Age	0.001	-0.003	0.002	0.001	-0.003	-0.002
	(0.002)	(0.003)	(0.004)	(0.002)	(0.002)	(0.003)
Subsidy	-0.062	-0.071	-0.189***	-0.005	0.016	-0.05
	(0.073)	(0.132)	(0.07)	(0.053)	(0.1)	(0.059)
Fixed Effects						
Province-Year	Yes	Yes	Yes	Yes	Yes	Yes
Power Type-Year	Yes	Yes	Yes	N.A.	N.A.	N.A.
Year	Yes	Yes	Yes	Yes	Yes	Yes
Firm	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,572	569	497	2,593	1,066	1,322
R^2_Adj	0.927	0.956	0.905	0.828	0.878	0.778

Notes: Columns (1) and (4) report estimates from the baseline model, as in columns (4) and (7) in Table 2. Columns (2) and (5) assume that the vertical unbundling had occurred in 2001 instead of 2003 and focused on the observations between 2000 and 2002 only. Columns (3) and (6) restrict observations to a balanced panel during the period 20002007. The dependent variable is natural logarithm of firm TEP measured by the Levionsohn and Petrin (2003) approach. In generation sector, Unb is an indicator variable that equals zero for firms belonging to 13 local electricity enterprises and one for firms affiliated with five generation companies that were separated from SPC, and in transmission sector it is equal to zero for firms belonging to 13 local electricity enterprises and one for firms affiliated with two transmission companies that were separated from SPC. Post03 equals zero for 2000-2002 and one for 2003-2007. Ln(labor) is the natural logarithm of the total number of employees in each firm. SOE is the ratio of the state-owned investments for each firm. Subsidy is a dummy variable indicating whether the firm received any subsidy from the state. Standard Errors are clustered at the level of the firm and reported in parentheses. N.A. denotes the fixed effects are non-existent because of only one industry in transmission sector. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels respectively. R^2_Adj refers to adjusted R^2 which considers the observations and the number of independent variables.

Table 4: Robustness Checks of Alternative TFP Estimates

	Generation Sector				Transmission Sector			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Baseline	OLS	FE	ACF	Baseline	OLS	FE	ACF
	Ln(TFP)	Ln(TFP)	Ln(TFP)	Ln(TFP)	Ln(TFP)	Ln(TFP)	Ln(TFP)	Ln(TFP)
Unb×Post03	-0.368***	-0.214	-0.374***	-0.394***	0.284***	0.362***	0.332***	0.322***
	(0.123)	(0.139)	(0.123)	(0.124)	(0.063)	(0.068)	(0.065)	(0.064)
Ln(Labor)	0.161*	-0.356***	0.061	-2.525***	0.062	-0.404***	-0.143*	0.247***
	(0.097)	(0.077)	(0.099)	(0.106)	(0.082)	(0.077)	(0.078)	(0.084)
SOE	-0.104	-0.1	-0.104	-0.105	-0.013	0.013	0.001	-0.004
	(0.064)	(0.073)	(0.065)	(0.066)	(0.057)	(0.059)	(0.058)	(0.057)
Age	0.001	-0.001	0.001	0.002	0.001	-0.000	0.000	-0.003
	(0.002)	(0.003)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Subsidy	-0.062	-0.085	-0.061	-0.058	-0.005	-0.03	-0.02	-0.016
	(0.073)	(0.085)	(0.073)	(0.073)	(0.053)	(0.052)	(0.052)	(0.052)
Fixed Effects								
Province-Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry-Year	Yes	Yes	Yes	Yes	N.A.	N.A.	N.A.	N.A.
Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,572	1,572	1,572	1,572	2,593	2,593	2,593	2,593
R^2_Adj	0.927	0.598	0.923	0.967	0.828	0.685	0.75	0.84

Notes: The table reports results using alternative TFP estimates. The dependent variable is natural logarithm of firm TEP in all specifications, while TEP is measured by the Levinsohn and Petrin (2003) approach in columns (1) and (4), and the OLS approach in columns (2) and (6), and the Fixed Effect approach in columns (3) and (7), and the ACF (Ackerber et al., 2015) method in columns (4) and (8). In generation sector, Unb is an indicator variable that equals zero for firms belonging to 13 local electricity enterprises and one for firms affiliated with five generation companies that were separated from SPC, and in transmission sector it is equal to zero for firms belonging to 13 local electricity enterprises and one for firms affiliated with two transmission companies that were separated from SPC. Post03 equals zero for 2000-2002 and one for 2003-2007. Ln(labor) is the natural logarithm of the total number of employees in each firm. SOE is the ratio of the state-owned investments for each firm. Subsidy is a dummy variable indicating whether the firm receives any subsidy from the state. N.A. denotes the fixed effects are non-existent because of only one industry in transmission sector. Standard Errors are clustered at the level of the firm and reported in parentheses. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels respectively. R^2_Adj refers to adjusted R^2 which considers the observations and the number of independent variables.

Table 5: The Mechanism of the Vertically-Unbundled Reform in Generation Sector

	(1) Baseline Ln(TFP)	(2) Low *FGIT* ln(TFP)	(3) High *FGIT* ln(TFP)	(4) County ln(TFP)	(5) City ln(TFP)
Unb×Post03	-0.368***	-0.463	-0.321**	-0.959**	-0.149
	(0.123)	(0.308)	(0.159)	(0.463)	(0.118)
Ln(Labor)	0.161*	0.273*	0.194	0.377**	0.019
	(0.097)	(0.148)	(0.146)	(0.178)	(0.079)
SOE	-0.104	-0.048	-0.146	-0.076	-0.104
	(0.064)	(0.089)	(0.089)	(0.15)	(0.079)
Age	0.001	0.001	0.001	0.003	-0.001
	(0.002)	(0.004)	(0.004)	(0.004)	(0.003)
Subsidy	-0.062	-0.194*	0.066	-0.079	-0.095
	(0.073)	(0.107)	(0.107)	(0.134)	(0.091)
Fixed Effects					
Province-Year	Yes	Yes	Yes	Yes	Yes
Power Type-Year	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes
Firm	Yes	Yes	Yes	Yes	Yes
Observations	1,572	657	915	767	805
R^2_Adj	0.927	0.939	0.916	0.875	0.892

Notes: Column (1) reports estimates from the baseline model as in Table 2 column (1). Columns (2) and (3) report results of subsample regressions where the sample is split according to the median *FGIT* level of each county. The level of *FGIT* is measured by the average ratio of total capital stock in the generation sector over total capital stock in the entire electricity industry of a specific county in the year of 2000. Column (4) and (5) report subsample regressions where the sample is split based on whether the firm is located in cities or counties. The time period is 2000-2007. The dependent variable is natural logarithm of firm TFP measured by the Levionsohn and Petrin (2003) approach. Unb is an indicator variable that equals zero for firms belonging to 13 local electricity enterprises and one for firms affiliated with the five generation companies that were separated from SPC. Post03 equals zero for 2000-2002 and one for 2003-2007. Ln(labor) is the natural logarithm of the total number of employees in each firm. SOE is the ratio of the state-owned investments for each firm. Subsidy is a dummy variable indicating whether the firm received any subsidy from the state. Power type includes fossil-fueled, thermal, and others. Standard Errors are clustered at the level of the firm and reported in parentheses. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels respectively. R^2_Adj refers to adjusted R^2 which considers the observations and the number of independent variables.

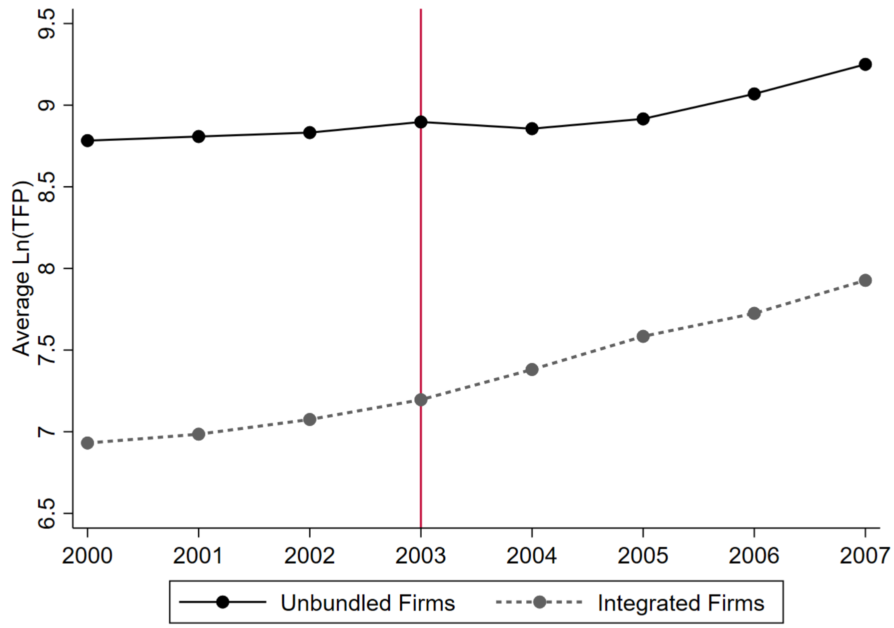
Table 6: The Mechanism of the Vertically-Unbundled Reform in Transmission Sector

	(1) Baseline Ln(TFP)	(2) Low *FGIT* ln(TFP)	(3) High *FGIT* ln(TFP)	(4) County ln(TFP)	(5) City ln(TFP)
Unb_Post03	0.284***	0.271**	0.322***	0.325***	0.259*
	(0.063)	(0.133)	(0.076)	(0.084)	(0.137)
Ln(Labor)	0.062	0.144	-0.046	0.159	-0.054
	(0.082)	(0.088)	(0.152)	(0.128)	(0.129)
SOE	-0.013	-0.002	-0.034	0.020	-0.04
	(0.057)	(0.079)	(0.087)	(0.089)	(0.092)
Age	0.001	-0.001	0.003	-0.001	0.002
	(0.002)	(0.003)	(0.003)	(0.003)	(0.004)
Subsidy	-0.005	0.003	0.008	0.027	-0.049
	(0.053)	(0.080)	(0.076)	(0.072)	(0.091)
Fixed Effects					
Province-Year	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes
Firm	Yes	Yes	Yes	Yes	Yes
Observations	2,593	1,174	1,419	1,542	1,051
R^2_Adj	0.828	0.81	0.843	0.806	0.833

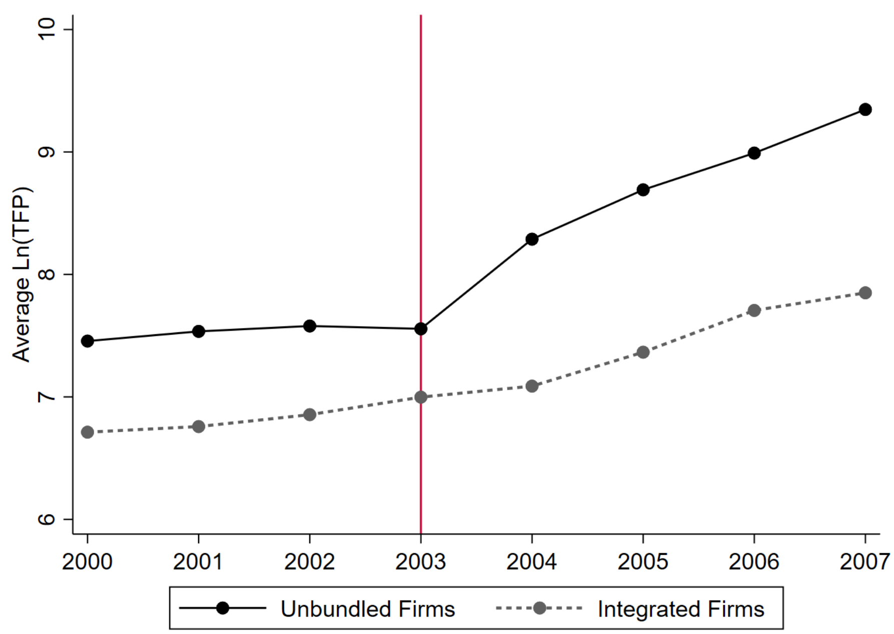
Notes: Column (1) reports estimates from the baseline model as in Table 2 column (5). Columns (2) and (3) report results of subsample regressions where the sample is split according to the median *FGIT* level of each county. The level of *FGIT* is measured by the average ratio of total capital stock in the generation sector over total capital stock in the entire electricity industry of a specific county in the year of 2000. Column (4) and (5) report subsample regressions where the sample is split based on whether the firm is located in cities or counties. The time period is 2000-2007. The dependent variable is natural logarithm of firm TFP measured by the Levionsohn and Petrin (2003) approach. Unb is an indicator variable that equals zero for firms belonging to 13 local electricity enterprises and one for firms affiliated with two transmission companies that were separated from SPC. Post03 equals zero for 2000-2002 and one for 2003-2007. Ln(labor) is the natural logarithm of the total number of employees in each firm. SOE is the ratio of the state-owned investments for each firm. Subsidy is a dummy variable indicating whether the firm received any subsidy from the state. Standard Errors are clustered at the level of the firm and reported in parentheses. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels respectively. R^2_Adj refers to adjusted R^2 which considers the observations and the number of independent variables.

Figure 1: Evolution of Productivity in Electricity Industry, 2000-2007

Panel (a) Generation Sector



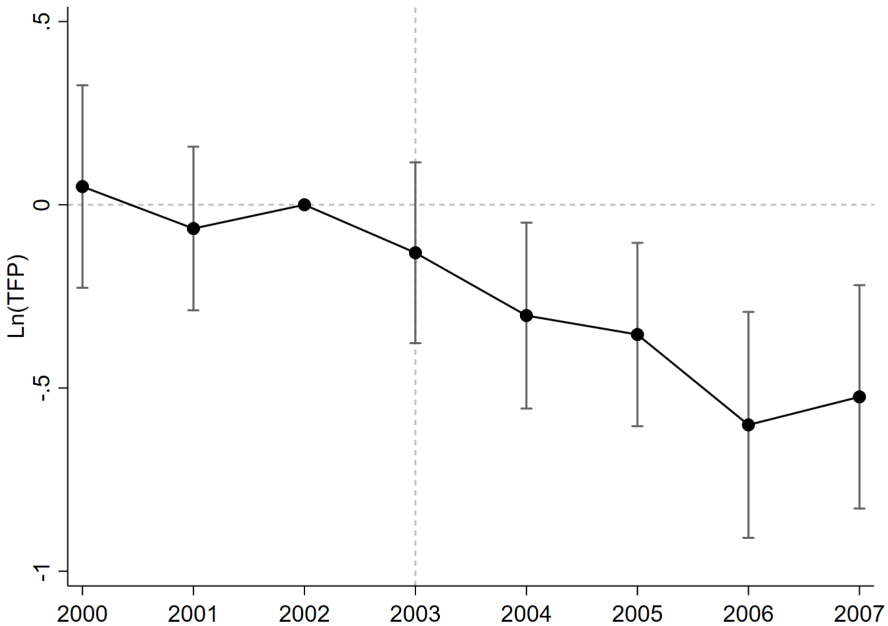
Panel (b) Transmission Sector



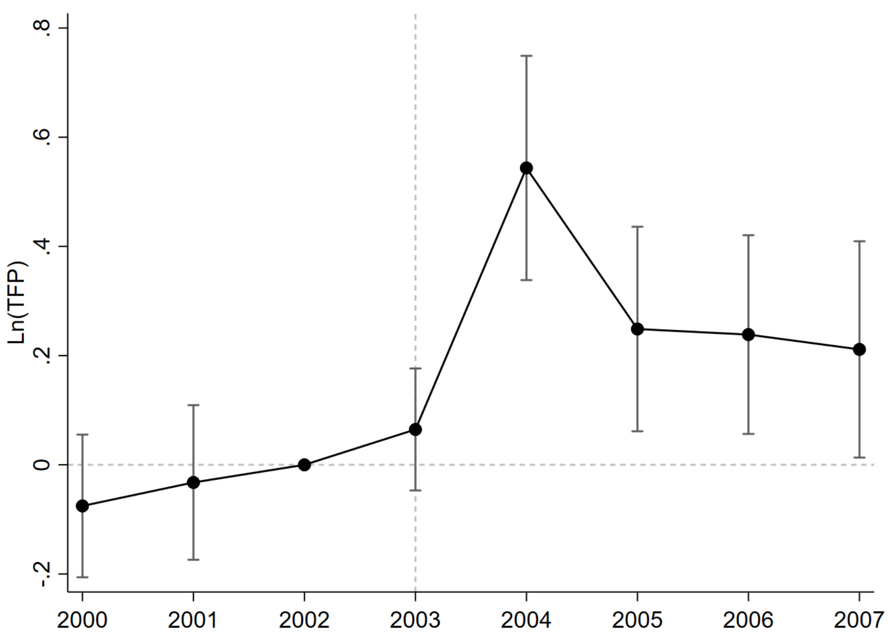
Notes: The figure plots firm productivity, measured as TFP, for the generation and transmission sectors, respectively. Each data point is the labor-weighted annual average Ln(TFP) of all the vertically-unbundled firms or the vertically-integrated firms in our sample. TFP is measured by the Levinsohn and Petrin (2003) approach. The restructuring of the electricity industry was implemented in 2003.

Figure 2: Difference-In-Difference Estimates

Panel (a) Generation Sector



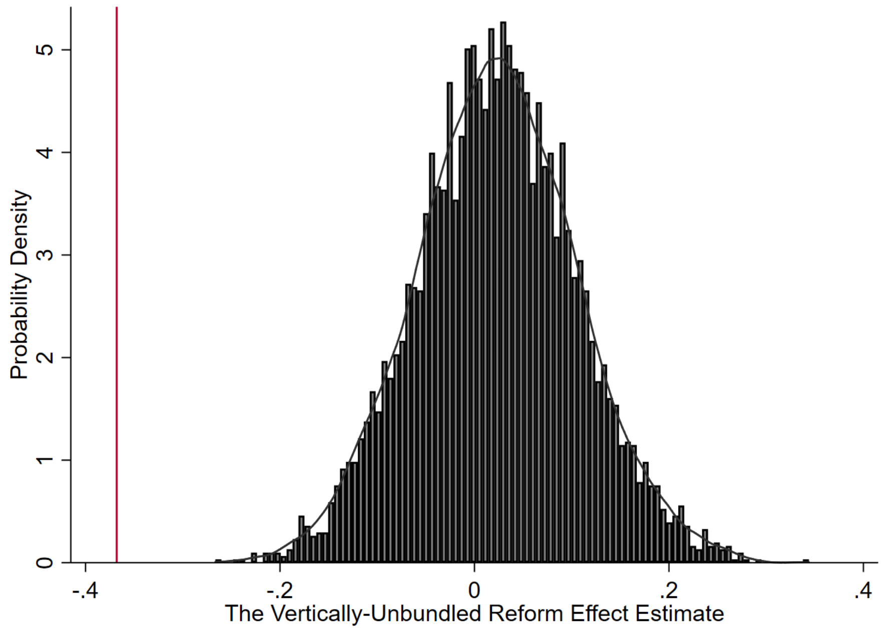
Panel (b) Transmission Sector



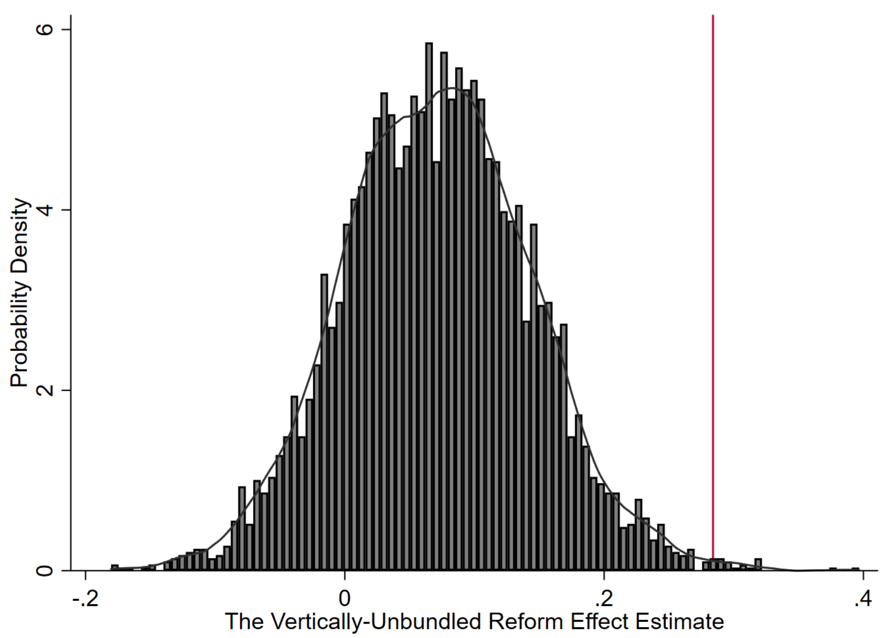
Notes: The figure illustrates the results from the baseline model in Equation 8 where the dependent variable is natural logarithm of firm TFP measured by the Levinsohn and Petrin (2003) approach. The black dots represent the estimated coefficients on the interaction terms between time indicators and a dummy for firms which were vertically-unbundled in 2003. The gray bars denotes 95 percent confidence intervals of the point estimates based on standard errors clustered at the level of the firm.

Figure 3: Distribution of Estimated Coefficients of Falsification Test

Panel (a) Generation Sector



Panel (b) Transmission Sector



Notes: The figure depicts the distribution density of the estimated coefficients from 5000 simulations that randomly assign the vertically-unbundled status to the firms in the generation sector (Panel (a)) and the transmission sector (Panel (b)), respectively. The vertical lines present the results of the baseline models, which are summarized in columns (4) and (7) in Table 2.

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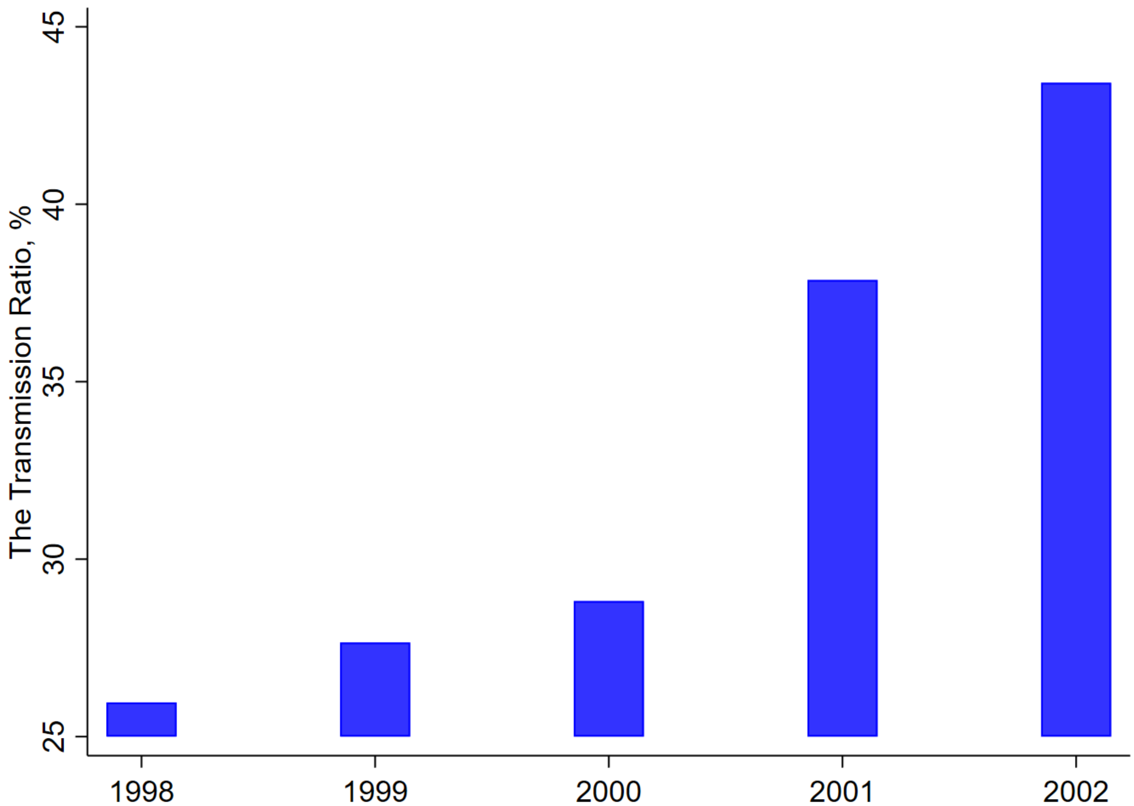
Appendices

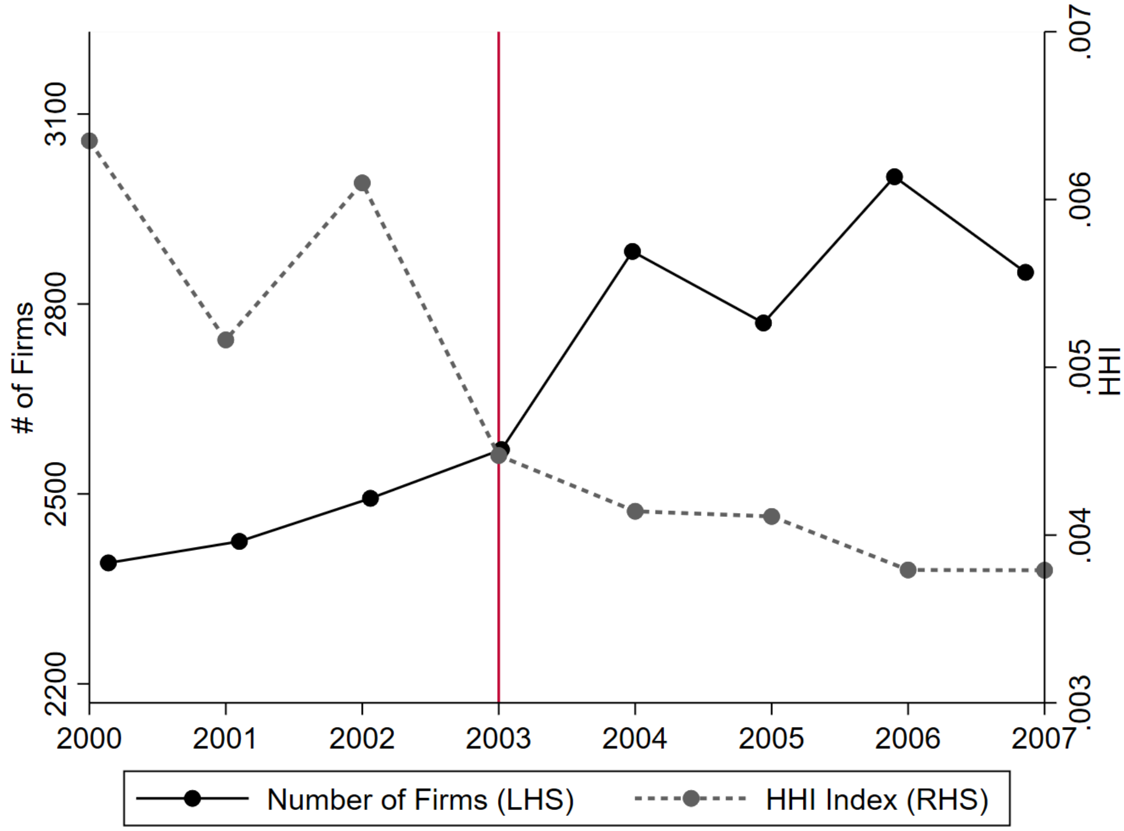
A Additional Figures

Figure A.1: Evolution of the Transmission Sector Investments



Notes: the figure plots the percentage of the investments of the transmission sector among all investments of China's electricity industry. The values are the authors' calculation based on the data from China Electric Power Yearbook. http://tongji.cnki.net/kns55/navi/HomePage.aspx?id=N2012030034&name=YZGDL

Figure A.2: Evolution of Competition Intensity in Electricity Generation Sector



Notes: the figure plots the annual number of firms and HHI index for the electricity generation sector. The values are the authors' calculation based on the data of the Above-scale Industrial Firms Panel, provided by China's National Bureau of Statistics. http://www.stats.gov.cn/