Economies of Scale or Specialization? The Impact of Vertical Unbundling on Firm Efficiency 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 because of intensified competition and enhanced autonomy but could also negatively affect the productivity because of the loss of synergy and scaled economy. By exploiting the vertical unbundling that took place in China in 2003, this study finds that vertical unbundling increased the labor use of the generation firms and the material use of the transmission firms. Additional investigation reveals that generation firms suffer from an efficiency loss in labor use due to the loss of coordination after vertical unbundling and the transmission firms face an increased transaction cost in acquiring material and bear the additional cost transferred from the efficiency loss of the upstream generation firms. Our findings suggest that benefits of vertical unbundling relative to integration critically hinge on the market structure of the industry.

Keywords: vertical unbundling, electricity industry, efficiency, integration
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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; Arocena et al., 2012; 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 inputs, personnel, management, information 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 (Bushnell and Wolfram, 2005; 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).

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[2], 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 the important roles of the upstream and downstream structure of the generation and transmission sectors in the electricity industry and the market structure in each sector in determining the benefits of specialization relative to integration.

During vertical-integration, generation firms enjoy more benefits from sharing of human capital with the transmission firms and many generation firms did not have independent sales and accounting departments as their primary goal is to provide intermediate input (electricity) for the transmission sector. Therefore, when vertically unbundled, the generation firms would suffer an efficiency loss in the labor use from the loss of coordination advantages when they start to operate as independent entities that incorporate both production and sales. Moreover, the transmission sector, being the

[2] 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.

downstream player, would face an increased transaction cost in acquiring their material input (electricity) when separated from an integrated firm and also needs to bear the additional cost transferred from the upstream generation firms due to their efficiency loss in labor input. The major justification of vertical unbundling is that dividing an integrated electricity company into independent generation and transmission firms would foster competition within the industry and thus improve the efficiency. However, this efficiency gain is only limited to the generation sector because the transmission firms may still possess monopolistic power as transmission grid and distribution lines feature network characteristics associated with a natural monopoly. The efficiency gain from the more intensified competition in the generation sector also needs to be weighed against the efficiency loss from the loss of coordination advantages and the cost transferred to downstream transmission firms.

Through a difference-in-difference framework built upon the model of Fabrizio et al. (2007) and Gao and Van Biesebroeck (2014), this study estimates the impact of the vertical unbundling restructuring of the Chinese electricity market in 2003 on the efficiency in input demand (labor and material) of both the generation and transmission firms, relying on a balance panel of firm-level data from the Above-scale Industrial Firms Panel of China for the years of 2000-2007. We empirically estimate the impacts of vertical unbundling by comparing the input demand of both the generation and transmission firms previously managed by the State Power Company (SPC) and thus experienced vertical unbundling with that of the firms managed by other independent enterprises that were unaffiliated with SPC and thus remained their original organizational form. To more accurately identify the firms that belonged to SPC, we manually collect the information of the shareholder and ultimate beneficiary of each electricity firm through an online platform that provides the registration information of all registered social entities in China. In order to address the concern that the estimated treatment effects could be driven by firm differences, we include a rich set of firm-level covariates and heterogeneous year fixed effects that vary by firm size, power type and province. With this demanding analysis, our benchmark results show that the vertical unbundling increases the labor input of the generation firms by 14.9 percent and the material use of the transmission firms by 29.5 percent. Our estimates are not heavily influenced by the differences in the characteristics between the control and treatment groups as they survive various robustness checks by using Entropy Balancing and different matching methods (CEM and PSM) and restricting the comparison between firms that are located within certain distance. Our mechanism analysis reveals that the generation firms that are located in the cities where the generation and transmission sectors were more integrated before the restructuring experienced a larger efficiency loss in labor use after vertical unbundling due to larger loss of synergy, and the transmission firms that are located in regions where labor use in the generation sector grows faster suffer a lager increase in material expense from the cost transfer from the upstream sector. In addition, the increased competition only mitigates part of the negative impact of the loss of synergy, as we find that in the cities where the generation sector faces more intensified competition post-restructuring, the generation firms suffered less efficiency loss in labor use and the transmission firms thus experienced a smaller increase in material use. The competition effects are not able to fully offset the negative impact of vertical unbundling since state-owned generation firms continue to enjoy government subsidies in coal (the primary fuel source of electricity generation in China) and have better connection with transmission companies because of their long-term historic ties, and thus have less incentive to increase their efficiency in input use compare with independent generation firms. Moreover, the competitive wholesale bidding reform was not successful and was eventually suspended after several trials, failing to sufficiently foster competition within the electricity generation sector.

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. Our study is mostly related to Gao and Biesebroeck (2014) who 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. However, our study differs from their study in several important ways. First, Gao and Biesebroeck (2014) identified the firms that were officially denoted as state-owned in 2002 as treated firms that experienced vertical unbundling in their benchmark analysis while our study identifies that firms that belonged to SPC as the treated firms, which we believe is a more accurate measure of the firms that experienced vertical unbundling. Unlike their findings that vertical unbundling had a positive impact on the efficiency of labor use of the generation firms, we find a negative impact as the restructuring increases the firms' labor use. The discrepancy of the findings exists because we define the treatment group in a different way and we include more control variables and only focus on the firms that operated throughout the entire data period. Second, their study and most other existing studies of the related subject only explore the impact of the restructuring on the generation sector and ignore the spillover effects on downstream firms, while our study investigates both the generation and transmission firms, which provides a more complete assessment of the vertical unbundling on the entire electricity industry. The efficiency gain from the increased competition in the generation sector alone is not enough to justify the vertical unbundling as a more efficient organizational form because the benefits need to be evaluated against any efficiency loss imposed on the entire industry, especially with the upstream and downstream structure in 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 Kaserman and Mayo (1991); 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); De Nooij and Baarsma, 2009; 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 mainly due to variable cost synergies. 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 impacts of restructuring are related to the market structure 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 critically affects the electricity accessibility and wellbeing of Chinese households, which has important welfare implications. Third, our finding that the effectiveness of the restructuring depends on the market structure 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.

The paper proceeds as follows. Section 2 briefly describes the industry and policy background of the study and the data. Section 3 describes the empirical strategy. Section 4 presents the estimation results and mechanism analysis and Section 5 concludes.

2 Industry Background and Data Description

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 reform in the years following 2002. To remove the monopoly of the SPC and introduce the competition in the generation sector, in December 29th of 2002, the State Council launched formally the reform that separated the generation sector from the transmission sector, which took effect in 2003. At that time, it was widely expected that the unbundling and deregulation reform would eventually improve the efficiency of the entire industry, through specialization and increased competition. 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[3]. Each of the companies has its own subsidiaries and in the empirical analysis, we consider the firms that belong to the Big Five and the two transmission companies that were separated from SPC as the firms that experienced vertical unbundling. The remaining independent generation and transmission companies that were not affiliated with SPC were not affected by the restructuring and thus remained their original organizational form.

2.2 Data and Summary Statistics

Our primary data source is the firm-level data of the Above-scale Industrial Firms Panel,

[3] 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.

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 an important control in input demand equation, 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 firms, we select those firms that belong to codes 441 (generation sector) and 442 (transmission sector) under Chinese Industrial Classification. To remove the effects of the firm's entry and exit, we only consider the firms that stayed operating during the period 2000-2007 (balanced panel). Finally, we end up having 59 treatment firms and 641 control firms in the electricity generation sector, and 694 treatment firms and 141 control firms in the electricity transmission sector. Figure 1 depicts our definition of control and treatment groups based on whether each firm belongs to the former SPC. To facilitate our definition of the control and treatment groups, we manually collect information of the shareholder and ultimate beneficiary of each firm and the details will be provided in Section 3.2.

We focus on several firm characteristics in our analysis. The dependent variables are two inputs, labor and material, which are in natural logarithmic form. Labor measures the total number of employees of each firm, and material denotes a firm's intermediate input expenditure in value terms, containing the expenses of both fuel and non-fuel inputs.

Five firm covariates are included in our empirical model, including capital stock, revenue, wage, SOE and age. The first three are in natural logarithmic form. Capital stock is a measure of firm size, calculated in perpetual inventory method. Revenue is total output values in each firm. Wage is defined as the total labor compensation, including wage and nonwage expenditures, over the firm's total employees. Age measures the number of years a firm has been in operation. SOE is the ratio of equity owned by state.

Table 1 reports pre-reform summary statistics on the main variables used in the following analysis for the balanced panel of generation and transmission firms. On average, in the electricity generation sector, without controlling for anything, the firms in the treatment group take significantly higher labor and material demands relative to the control group as the firms that belonged to SPC are generally larger than the other independent firms. As for the covariates, firms in the treatment group also have more capital, more revenues and higher wages, but less state share. In terms of the age, the difference between the control and treatment firms is smaller in statistical significance relative to the other variables. In the transmission sector, the firms in the treatment group demand more labor and material inputs, and have more capital, more revenue, higher wages and are generally older than those in the control group, since the transmission firms that were affiliated with SPC have larger sizes and were established earlier. However, there is no significant difference between the two groups in terms of state share. In the empirical analysis, we will control for these underling differences in firm characteristics.

To alleviate the concern that the estimated treatment effects are influenced by the differences in firm characteristics, Ln(K), Ln(Revenue), Ln(Wage), SOE and Age are weighted by Entropy Balancing, in some specifications in our empirical analysis. The Entropy balancing method is proposed by Hainmueller (2012) to achieve covariate balance in observational studies with binary treatments and reduce model dependence for the subsequent estimation of treatment effects. This method is widely used in the economic literature (Marcus, 2013; Neuenkirch, 2016; Ogrokhina and Rodriguez, 2019; Ohrn, 2019). The method calibrates unit weights so that the means of the covariates in the treatment group match that in the control group. After assigning the vector of balancing weights to the firms in the control group, with weights equaling one for the firms in the treatment group, there no longer exists any significant differences between the treatment and control groups in terms of firm characteristics, in both generation and transmission sectors (Table 1). Consequently, we are confident that the control group is comprised of credible counterfactuals for the firms that experienced vertical-unbundling. In Section 4, we use Entropy Balancing method to verify that our estimates of the treatment effects are not heavily influenced by the differences in firm characteristics and are robust to different methods in addressing sample selection.

3 Empirical Framework

3.1 Empirical Model

To explore the impact of the vertical unbundling on the efficiency of firm production, it is necessary to specify a production function and then derive the relevant input demand by cost minimization at a given level of output (Fabrizio et al., 2007). Considering the material demand was highly inelastic in electricity industry, Gao and Van Biesebroeck (2014) made a few modifications of Fabrizio et al. (2007), positing the Leontief functional form for the production function to reflect no substitution between material and other production factors like labor and capital. Based on the setting, Gao and Van Biesebroeck (2014) derived a first-order Taylor approximation to the labor (L) demand equation in log-linear form:

$$\ln L_{it} = \alpha_1 \ln Q_{it} + \alpha_2 \ln W_{it} + \alpha_3 \ln K_{it} + \alpha_i + \phi_t + \varepsilon_{it}^L \quad (1)$$

Similarly, the equation for material (M) demand is

$$\ln M_{it} = \beta \ln Q_{it} + \beta_i + \phi_t + \varepsilon_{it}^M \quad (2)$$

where Q is the output, W is the wage and K is the capital input that is supposed to be quasi-fixed in the short run; α_i and β_i are the firm-specific effects that measure the variation in input use across firms arising from heterogeneous technologies, city fixed factors, and basic efficiency differences; ϕ_t represent common annual changes that all firms experience; ε denotes unobserved mean zero shocks for labor and material demand.

Because data on material inputs and electricity output in physical quantities are not available, Gao and Van Biesebroeck (2014) use input expenditures and electricity revenue instead. Hence, after controlling for industry-level average price variation using time dummies, firm-specific deviations from average input and output prices became omitted variables, which could bias the estimate of the restructuring effects (missing price bias). To combat this concern, Gao and Van Biesebroeck (2014) employ a set of interaction terms, including firm size, age and the share of state-owned interacted with province dummies to control for the difference between firm-specific and industry-level average prices implicitly.

Similar to Gao and Van Biesebroeck (2014), we exploit the natural experiment of the 2003 reform of China's electricity market to investigate the impact of vertical unbundling on firm's efficiency and conduct our empirical analysis in a difference-in-differences (DID) framework. Based on the labor and material input demand equations, we compare the changes in the two input demand before and after the 2003 restructuring between the electricity firms who were directly impacted by the restructuring and those that did not experience vertical unbundling.

Different from Gao and Van Biesebroeck (2014) who only investigated the electricity generation sector, we examine the impact of vertical unbundling on both the generation and transmission firms, which provides a more thorough evaluation of the effects of vertical unbundling on the entire electricity industry. We basically estimate the efficiency increase or decrease of the vertically unbundled firms relative to the firms that remained their original organizational structure after the reform. To estimate the causal effects of the vertical unbundling reform, our identification strategy is mainly based on the following DID models originated from equations (1) and (2):

$$\ln(Labor_{it}) = \gamma_L (Unb_i \times Post03_t) + \alpha_1 \ln(Revenue_{it}) + \alpha_2 \ln(Wage_{it}) + \theta X_{it} + \alpha_i + \phi_t + \varepsilon_{it}^L \quad (3)$$

$$\ln(Material_{it}) = \gamma_M (Unb_i \times Post03_t) + \beta_1 \ln(Revenue_{it}) + \varphi X_{it} + \beta_i + \phi_t + \varepsilon_{it}^L \quad (4)$$

where Unb_i is an indicator variable that equals one if firm i is in the treatment group (experienced vertical unbundling), and zero if it was in the control group (remained original organizational form). Specifically, for the electricity generation sector, the generation firms that were affiliated with the Big Five generation companies, experiencing the vertical unbundling, are in the treatment group, and the others are defined as control group. Similarly, in the transmission sector, the firms that belonged to the two transmission companies separated from SPC are in the treatment group, and the remainder that operated in their original organizational structure are classified into the control group. We will further discuss the classification of firms according to their ownership in the following subsection. $Post03_t$ is a dummy variable that equals one for the years 2003 and onward, and zero for the years before 2003, since 2003 is the first year that the reform was officially implemented. γ_L and γ_M are the coefficients of interest, which are the estimates of the interaction between the vertical unbundling indicator and post-2003 dummy. These two coefficients measure the improvement (negative sign) or decrease (positive sign) in input efficiency of labor and material input of the electricity firms that experienced vertical unbundling, relative to the firms that remained their original organizational form after the reform. As pointed out in the introduction, due to the difference of the market structure and the upstream and downstream industry relationship, we would expect the treatment effect to be positive (efficiency loss) for labor demand while uncertain for material demand in the generation sector. Meanwhile, the treatment effect for material demand is expected to be positive (efficiency loss), but that for labor demand is uncertain in the transmission sector. The set of α_i and β_i represent firm fixed effects, which control for time-invariant firm-level differences that affect firm input demand, such as the city where the firm is located, firm technology and basic efficiency, etc. X_{it} is a vector of time-varying variables, including firm covariates such as size, the share of state-owned and age, and their interaction with province dummies to control for the firm-specific deviations from the industry-level average prices of material and electricity. 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 firms (fossil-fueled, thermal, and others) and the province where the generation firms are located. For the transmission sector, we include the interaction terms of province and year dummies to control for the regional shocks over time for the transmission firms.

In order to study the dynamic response of the firm's input use to the 2003 reform, we run the following regression specifications:

$$\ln(Labor_{it}) = \sum_{\substack{j=2000 \\ j\neq 2002}}^{2007} \gamma_j^L (Unb_i \times Year_j) + \alpha_1 \ln(Revenue_{it}) + \alpha_2 \ln(Wage_{it}) + \theta X_{it} + \alpha_i + \phi_t + \varepsilon_{it}^L \quad (5)$$

$$\ln(Material_{it}) = \sum_{\substack{j=2000 \\ j\neq 2002}}^{2007} \gamma_j^M (Unb_i \times Year_j) + \beta_1 \ln(Revenue_{it}) + \varphi X_{it} + \beta_i + \phi_t + \varepsilon_{it}^L \quad (6)$$

Where all variables are defined as before except $Year_j$ that is a dummy variable for year j over 2000-2007, excluding 2002 that serves as the baseline reference. The dynamic effects are reflected by the coefficients γ_j^L and γ_j^M, which allow us to investigate the changes of input use of the firms that experienced the vertical unbundling relative to the firms that did not, for each of the years around the 2003 reform. The pre-2003 trends indicate whether there existed a pre-existing trend of firm input use for the treated firms relative to the control firms, and the absence of a pre-existing trend could boost the confidence that the changes of input use in the treatment group relative to the control group after the 2003 reform is mainly due to the restructuring effect.

3.2 Identification of Treated Firms

The vertical integration was effectively unbundled in 2003, dismantling the State Power Company and divesting its generation assets into the Big Five generation companies and its transmission and distribution assets into two transmission companies. By the end of 2010, the Big Five generation companies, made up of many local power firms, were located in different regions in China (Panel A in Figure 3) and accounted for about half of the total electricity capacity in China (Zhao and Ma, 2013), but none of them owned more than 20% market share in any of the new power regions (Gao and Biesebroeck, 2014). The two transmission companies, consisting of a large number of grid firms, are the two dominant players in the electricity transmission sector, with their grids covering the most parts of China (Panel B in Figure 2).

Despite the vertical unbundling reform at the national scale, numerous firms that did not belong to SPC were not affected and thus remained the original organizational structure. For example, 15 independent local electricity companies located in 11 provinces[4] that own independent generation and transmission firms, were not directly impacted by the restructuring reform in 2003, and retained their vertically integrated operation. The reasons why they operated independently from the SPC are mainly historical and geographical: these electricity companies were generally located in the areas with abundant coal or water resources, and thus could basically meet the electricity demand from local users. In addition, in the generation sector, the power firms owned by private and foreign companies, which were not owned by SPC, did not experience the vertical unbundling either, which could also serve as the control group. Those private and foreign-owned generation firms were established during the diversified investment financing reform in the electricity generation sector starting 1985, as mentioned in Section 2.1. Different from the generation sector, the Chinese government did not allow any private and foreign investment in the electricity transmission sector. Therefore, the transmission firms that belonged to the two transmission companies separated from SPC should be defined as treated firms, with the remaining independent transmission firms classified into the control group. Figure 1 depicts the general structure of the electricity industry in China.

In the generation sector, we select the firms that were affiliated with the Big Five generation companies as the treatment group, similar to Du et al (2008). The remaining firms that operated in their original organizational form, are defined as the control group. To provide a more accurate identity of firm ownership, we use Celestial Eye Survey (CES)[5], a commercial online platform providing basic registration information of 180 million social entities in China, to collect the information of the biggest shareholder and ultimate beneficiary of each electricity firm. Basically, if the biggest shareholder name or the ultimate beneficiary of a generation firm is one of the Big Five generation

[4] The 15 independent local electricity companies are Hubei Danjiang Electric Power Co., Ltd, Guangxi Guidong Electric Power Co., Ltd, Guangxi Baise Power Co., Ltd, Chongqing three Gorges Water Conservancy and Power Co., Ltd, Chongqing Wujiang Electric Power Co., Ltd, Hunan Jinyuan Electric Power Group Co., Ltd, Shanxi International Electric Power Group Co., Ltd, Jilin Local Hydropower Co., Ltd, Guangxi Water Conservancy and Electric Industry Group Co., Ltd, Shenzhen Investment and Power Supply Co., Ltd., Hunan Electric Power International Development Co., Ltd, Yunnan Baoshan electric power co., Ltd, Shaanxi local electric power co., Ltd, Sichuan Hydropower Investment and Management Group Co., Ltd, independent power grid of Shihezi Corps, separately. And the 11 provinces are Shanxi, Shaanxi, Sichuan, Chongqing, Guangxi, Guangdong, Jilin, Hunan, Yunnan, Hubei and Xinjiang, respectively.

[5] Information includes each firm’s year of establishment, shareholder name, ownership, scope of business, ultimate beneficiary, etc. The official website is https://www.tianyancha.com/.

companies, the firm is classified into the treatment group. Similarly, in the electricity transmission sector, the firms that belonged to the two transmission companies dismantled from SPC are identified as the treatment group, and the remaining are classified as the control group. Again, we use the CES tool to identify the firms in the treatment group by their biggest shareholder and ultimately beneficiary: if the biggest shareholder name or ultimate beneficiary of a transmission firm is one of the two transmission companies, it is defined as the treated firm. Figure 2 plots the geographic locations and relative size of the controlled and treated firms in the generation and transmission sectors.

4 Empirical Results

4.1 Main Results

In this section, we first use the baseline empirical models (3) and (4) to study the effects of the 2003 vertical unbundling on the labor and material input use of electricity firms, and then investigate the dynamic impacts of the restructuring, following (5) and (6). We estimate these equations for both the generation and transmission sectors.

4.1.1 Electricity Generation Sector

Table 2 reports the estimated results of the effects of vertical unbundling on the input use of generation firms using baseline models (3) and (4). In panel A of Table 2, Column (1) controls for revenue, wage, firm fixed effects and year fixed effects. The coefficient of Unb×Post03 term is positive and statistically significant at the 1% level, implying a relative efficiency loss of labor usage for the firms that experienced vertical unbundling, relative to the firms that remained their organizational structural. Column (2) further adds time-varying firm characteristics: firm size, the share of state-owned and age. Column (3) adds the interaction terms of firm size with year dummy variables to control for the possible discrepancy effects on input demand stemmed from firm size differences between the control and treatment groups over time; Column (4) adds the interactions of province dummy variables with firm size, the share of state-owned and age in order to control for the firm-specific deviations from the industry-level average input and output prices, as in Gao and Van Biesebroeck (2014); Column (5) adds the interactions of power-type dummies with year dummies to control for the differential trend in the generation sector of different power types and Column (6) finally adds the interaction terms of province dummies with year dummies to control for annual shocks to the electricity industry in each province. In all the above specifications, the coefficients of Unb×Post03 are similar in terms of magnitude, and maintain at least 95% statistically significant levels. Column (6) is our preferred specification, which finds a coefficient of 0.149, indicating that switching from vertical integration to specialization increased the labor input of the restructured firms by 14.9 percent relative to the firms remained their organizational form. This efficiency loss in labor usage translates to an additional 155 workers to be employed by each vertically-unbundled generation firm and a total of 9,116 workers for all affected firms, accounting for 2.5% of the total employment in the electricity generation industry. Our finding is close in magnitude to Gugler et al. (2017) who investigate 28 major European electricity utilities and estimate that the magnitude of economies of vertical integration between electricity generation and transmission can reach 14 percent for a median sized integrated utility in European Union, although their analysis is based on a quadratic cost function method.

As revealed in the comparison between control and treatment groups in Table 1, the firms that experienced the vertical unbundling differ from those that did not in terms of certain firm characteristics such as firm size. To alleviate the concern that these differences might influence our estimate of the treatment effects, in addition to allowing the firms with different sizes to have different year trends as in Columns (3)-(6), we further employ the Entropy Balancing method to match the treated and control firms based on the suite of firm covariates and re-estimate the treatment effect. As shown in Column (7), the estimated treatment effect using Entropy Balancing is similar to, though slightly larger than that in column 6, and statistically significant at 1% level. Therefore, the Entropy Balancing result indicates that our estimate of the effect of vertical unbundling is not heavily influenced by the differences between the treated and control firms in the firm characteristics. To summarize, in all specifications, we consistently find a positive coefficient of Unb×Post03, suggesting that the vertical unbundling lowers the efficiency of labor use of the generation firms separated from SPC, relative to the firms that remained their original organizational structure.

Panel (B) of Table 2 reports the impact of vertical unbundling on the demand of material input, which reveals a different pattern from labor input. Following the same order of adding the controls as the specifications for labor input, the corresponding regressions of material input in Columns (1)-(6) deliver a smaller but insignificant treatment effect[6], indicating that restructuring did not significantly influence the efficiency of material usage for the firms that experienced vertical unbundling relative to the firms that did not. Meanwhile, the treatment effect in column (7) is still unchanged in significance compared with columns (1)-(6), after employing Entropy Balancing method.

It's worth noting that our estimated treatment effect on labor input differs from the benchmark result of Gao and Van Biesebroeck (2014), who defined all state-owned firms as the treated firms. However, out result is similar to the result in their robustness check section, where they also defined the firms that belonged to the Big Five companies as the treated firms. Moreover, our result is also different from their study that finds a significantly negative impact of vertical unbundling on material input, even in the case where they defined the firms that were affiliated with the Big Five companies as the treated firms. We believe two differences between their study and ours lead to the discrepancy. First, we only include the firms that remained operation during our sample period to remove the influence on our estimated treatment impact from firm's entry and exits. Second, we use more demanding specifications by adding stricter controls in the baseline model. For instance, Gao and Van Biesebroeck (2014) only considers year effects that are constant to all firms, but we include the interactions of power type dummies with year dummies and interactions of province dummies with year dummies to control for the heterogeneous impacts of annual shocks in different

[6] In column 3, the treatment effect is statistically significant at the 10 percent level.

power types and regions.

To explore more closely the time structure of the treatment, we investigate the dynamic impacts based on models (5) and (6), using the same controls as in Column (6) of Table 2. Table 4 reports the coefficients of the interaction terms of the Unb variable with year dummies. In Column (1), the point estimates for years 2000 and 2001 are not statistically different from zero, revealing that the labor input of the treated and control firms grew with a similar trend before the restructuring reform took place. For years 2003-2007, the point estimates are significantly positive, indicating that labor usage of the firms that belonged to the Big Five companies increased relative to the firms that remained their original organizational structure after the restructuring. The gradually increasing estimates of 0.064 for 2003, 0.130 for 2004, 0.128 for 2005, 0.155 for 2006 and 0.168 for 2007 imply that the labor input difference between the treated and control firms amplifies annually after the restructuring. However, as implied in Column (2), the effects of vertical unbundling on the material input are insignificant overtime, no matter ex ante or post reform.

In sum, the dynamic effects of vertical unbundling on the generation sector in Table 4 echo our baseline estimates in Table 2 in two ways. First, the dynamic effect estimates confirm that the restructuring had a significant and positive impact on the labor use of generation firms, but an insignificant effect on the material use. Second, no discernible evidence is found for a differential trend between treatment and control groups existing in the years before the reform, which increases our confidence in the identification strategy.

4.1.2 Electricity Transmission Sector

Unlike the generation sector, the transmission sector features typical network characteristics associated with a natural monopoly and is in the downstream of the electricity industry with the output of generation sector as the primary material input. Hence, the impact of vertical unbundling on the input use in the transmission sector may be different from that in the generation sector. Table 3 reports the regression results based on the baseline models (3) and (4). Similar to Table 2, Column (1) presents results only including revenue, wage, firm fixed effects and year fixed effects as control variables; Column (2) adds additional firm covariates; Column (3) further adds the interaction terms of firm size with year dummies; Column (4) adds interactions of firm size, the share of state-owned and age, with province dummies. Ultimately, Column (5) adds the interactions of province dummies with year dummies, which serves as our preferred specification. Except for Columns (1) and (4), Panel A of Table 3 does not find a significant effect of vertical unbundling on the labor use of the firms that experienced vertical unbundling. To combat the concern that differences in firm characteristic might influence our estimate of the treatment effects, we use the Entropy Balancing method to match the treated and control firms using the firm covariate, as what we did in the generation sector. The estimated effect of vertical unbundling using the entropy balancing method in Column (6) remains virtually unchanged compared to that in Column (5). To sum up, the vertical unbundling did not have a significant impact on the efficiency of labor use for the transmission firms that experienced the vertical unbundling since they did not benefit from human capital sharing during vertical-integration as their labor requires completely different skills.

However, as shown in Panel (B) of Table 3, vertical unbundling did have an impact on the material input of the transmission firms that experienced vertical unbundling. By adding the controls in the same order as in the results of labor input, the estimated treatment effects across Columns (1)-(6) in Panel B are positive and statistically significant at 1% level, with similar magnitude, especially for Columns (5) and (6). The coefficient of Unb×Post03 in Column (5), our preferred specification, indicates that the restructuring increased the material use of the treated firms by 29.3 percentage points relative to that of the firms that remained integration. The estimated efficiency loss in material usage translates to an additional cost of 24,112 RMB (or 3,441 USD)[7] annually for each vertically-unbundled transmission firm and a total annual cost of

[7] The average annual material expense for a transmission firm in 2002 was 62,870 RMB (or 8,971 USD).

16,709,358 RMB (or 2,384,293 USD) for all affected firms, accounting for 31.9% of the annual total material expense in the electricity transmission sector.

Similar to the electricity generation sector, we estimate how the input use of the transmission firms respond to the restructuring dynamically following models (5) and (6) and using controls as in Column (5) of Table 3. Columns (3) and (4) in Table 4 report the dynamic effects of the restructuring over time in the transmission sector. For labor input, Column (3) illustrates that the restructuring did not have a significant impact on the treated firms relative to the control firms over 2000-2007. However, Column (4) finds that the estimated coefficients of the interactions of Unb with year dummies are small and not statistically significant for the years of 2000 and 2001, suggesting that material use of the firms that experienced the vertical unbundling and the firms that remained integration evolved similarly before the electricity reform. Unlikely the generation sector, the reform did not have an immediate impact on the transmission firms in 2003, but the material input of the treated firms witnessed a significant increase relative to the untreated firms in the following years, suggesting a lag in bearing the additional cost transferred from the generation sector. To summarize, the dynamic treatment effects in reported in Columns (3) and (4) of Table 4 validate ex post our identification strategy.

4.2 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. Based on the main findings in the previous subsections, the vertical unbundling only affects the labor use in the generation sector and the material use in the transmission sector, and thus we only consider these two variables in this subsection.

Some might be concerned that the changes of input demand may occur due to other policies that were introduced before the restructuring in 2003 or other unobserved shocks that could be correlated with the restructuring. To address this concern, the placebo test is conducted as a common practice in the existing 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 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 (1) in Table 5 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, for both the generation and transmission sectors. We then conduct an alternative placebo test method, similar to Cantoni 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. Figure 3 plots the distribution of the 5000 estimated placebo treatment effects, and also marks the actual treatment effect. Both panel (A) and panel (B) show that the actual estimate is located outside the entire distribution of the placebo estimates, supporting our argument that the effects of the vertical unbundling on the input demand of the treated firms in both the generation and transmission sectors are not caused by unobserved factors.

During the period from 2003 to 2007, Inner Mongolia, a province located in the north of China, implemented the vertical unbundling reform in 2004, one year later than the other provinces. But this reform did not separate the generation and transmission operations thoroughly, thus this province carried on a second round of divestiture in 2006, which might confound the estimated effect of the 2003 restructuring in our results. To address this concern, we conduct an additional robustness check by excluding all firms located in Inner Mongolia. Column (2) in Table 5 shows that the coefficient on labor use for generation firms and the coefficient on material use for transmission firms are quite close to our baseline estimates, in terms of both magnitude and statistical significance.

The geographical location generally affects the production efficiency of the generation firms partly due to differences in energy reserves such as coal and water resources, transportation convenience, as well as the demographics. While the firm fixed effects and a full set of province fixed effects interacted with year fixed effects in the baseline model mitigate these potential confounding effects, we further combat the concern by restricting the comparison between treatment and control groups using geographical distance matching that ensured similar geographical conditions among all selected firms. Specifically, we collect the geographic coordinates of each generation and transmission firm from Baidu Map and we restrict the firms in the control group to be less than 100 km, 200 km and 300 km away from the nearest firm in the treatment group, respectively. We report the corresponding treatment estimates for both the generation and transmission sectors in Columns (3)-(5) of Table 5. These results are all close to our baseline estimates, suggesting that the estimated treatment effects are robust to the geographical distribution of the generation and transmission firms.

To address the concern that differences in firm characteristics may influence our estimate of the treatment effects, we use multiple matching methods and re-estimate the model as a robustness check. The matching methods include the general Coarsened Exact Matching (CEM), one-by-one CEM that guarantee the same number of the treated and control firms by randomly dropping observations[8], and Propensity Score Matching (PSM) in the form of the nearest neighbor matching with logit model. We report the corresponding coefficients of vertical unbundling in Columns (6)-(8) of Table 5. All of these methods do not meaningfully alter the coefficient of interest in both the generation and transmission sectors, indicating that our results are robust to possible selection bias caused by difference in firm characteristics.

4.3 Mediating Mechanisms

Why does the vertical unbundling have large but asymmetric effects on the efficiency of input use of electricity generation and transmission sectors? Specifically, the restructuring significantly lowered the efficiency of labor use of the vertically-unbundled generation firms, but did not have a significant impact on their material

[8] This one-by-one CEM method can balance the covariates between the control and treatment groups, at the cost of losing a large number of observations if there exists notable difference between the treatment and control groups.

usage. However, for the transmission firms, the efficiency of material use of the treated firms notably declined relative to the firms that remained integration, while efficiency of labor use was not significantly impacted. In the following subsection, we explore potential channels in terms of the market structure to explain the discrepancy of the treatment effects found in the generation and transmission sectors.

4.3.1 The Effect of Vertical Integration

The economies of vertical integration between electricity generation and transmission lead to significant cost savings and the savings are larger for large-scale integrated utilities (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 financial 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). Therefore, the vertical unbundling would increase the coordination costs between the generation and transmission firms and the increased cost would be larger if the two sectors were more synergistic during vertical integration.

During vertical integration, the upstream generation firms would enjoy more benefits from synergy and human capital sharing. Being a downstream sector that directly serve the end users, transmission firms have relative strong sales departments whose labor is often shared with the generation firms if necessary. Many generation firms also did not have independent accounting and sales department during vertical integration as their primary goal is electricity production, providing input for the transmission firms. Therefore, when vertically-unbundled, as independent units, generation firms are no longer able to take advantage of the personnel and management of the transmission firms and need to form independent sales department, which requires more labor use. Being long used to only focusing on the production side, generation firms need to incur additional cost whey they establish their own sales department and begin to operate as independent entities that incorporates both production and sales. Transmission firms, on the contrary, do not benefit much from human capital sharing as they have their own sales team and their labor focuses more on electricity transmission and distribution, which requires different skills from the labor in the generation firms, who is specialized in electricity generation. Thus, we would not expect vertical unbundling to have a significant impact on the labor demand of the transmission firms.

The additional labor demand would be larger if the generation firms had benefited more from human capital sharing and coordination during vertical integration. Hence, we would expect that the restructuring increases the labor use more for the generation firms located in areas with a higher degree of vertical integration than those located in areas with a lower degree of vertical integration. In order to measure the degree of vertical integration, we use the median distance between generation and transmission firms in each city in 2002, and estimate heterogeneous treatment effects for the subsamples of firms located in cities whose distances are above or below the median level, respectively. The main assumption is that, if the generation firms are located within a shorter distance from transmission firms, the degree of synergy would be higher between the generation and transmission sectors due to a lowered transportation cost and the generation firms are more likely to share human capital with the transmission firms and thus suffer more from vertical unbundling by demanding more labor input. As shown in Columns (1)-(2) of Panel A in Table 6, in the cities with a higher degree of vertical integration (below-median distance), the vertical unbundling had a statistically significant and negative impact on labor input efficiency of the generation firms (an increase in labor demand), while no significant impact was found on that of the generation firms located in cities with lower degree of vertical integration (above-median distance). Meanwhile, the results in Columns (1)- (2) of Panel B in Table 6 imply that the vertical unbundling did not have a significant impact on the labor use efficiency of the transmission firms, no matter whether they are located in the cities with higher or lower vertical integration in the electricity industry, which coincides with our prior assumption.

Unlike labor whose certain skills could be applied to both generation and transmission firms, the two sectors rarely share materials because of the differences in the production process. Being an upstream firm, generation firms consume coal and water as their primary materials, while transmission firms, as a downstream player, use electricity produced from power plants as the main material in the production. Therefore, the generation sector does not enjoy any benefits from synergy and coordination of material usage when vertically-integrated, and we would not expect a significant impact of vertical unbundling on the material use of the generation firms, regardless the degree of integration. Columns (3)-(4) in Panel A of Table 6 confirm our conjecture and show that there is no measurable effect of the restructuring on the efficiency of material use in both cases of vertical integration.

Although the two sectors do not benefit from material sharing under vertical integration, the transmission sector does have a lower cost in acquiring the intermediate input (electricity), the major component of material demand, due to the lowered transaction cost within a vertically-integrated industry (Meyer, 2012). During the period of vertical integration, the transmission firms could enjoy more favorable electricity prices from the generation sector in the same business entity, which are usually lower than the prices offered by other independent power companies (Mansur, 2007; Bushnell et al., 2008). When vertically-unbundled, however, the transmission firms need to pay a higher price for the same unit of electricity because of the increased transaction cost either from searching for new generation firms to ensure the stability of power supply or negotiating with existing providers during the period of sharp rise in coal prices (Landon, 1983; Fetz and Filippini, 2010). Moreover, the increased input cost of the generation firms (upstream) due to the loss of labor input efficiency is likely to be transferred to the transmission firms (downstream) through the intermediate input prices, leading to additional efficiency loss from vertical unbundling. Consequently, we would expect the restructuring to increase the material expenses of the transmission firms, especially in the areas where the electricity generation sector experience a larger increase in labor demand after vertical unbundling. To check this possibility, we measure the degree of cost transfer by the median growth rate of employment of the generation firms between 2000-2002 (pre-restructuring) and 2003-2007 (post-restructuring) in each city, and run separate regressions for the subgroups of the transmission firms located in cities whose labor demand growth rates in the generation sector are below or above the median level. The estimated results in Columns (3)-(4) in Panel B of Table 6 suggest that the transmission firms located in the cities whose generation sector experienced faster growth in labor demand suffer from a larger efficiency loss in material input after vertical unbundling, compared with those located in the cities where the labor demand in generation firms increased modestly.

4.3.2 The Effect of Competition

The primary justification of vertical unbundling is that dividing an integrated power company into independent generation and transmission firms could increase the productivity of the industry by removing anticompetitive forces and fostering competition. However, the impact of vertical unbundling on the competition of the generation and transmission sectors could be heterogeneous due to their difference in terms of market structure. The generation firms may face more intensified competition after the restructuring while the transmission firms may still retain monopolistic power as transmission grid and distribution lines feature network characteristics associated with a natural monopoly. During the 2003 restructuring, the SPC's generation assets were divested into five generation companies that had no more than 20% market share in any of the new power-regions, which significantly boosted the competition among the generation firms. Hence, the generation firms should have a stronger incentive to increase the efficiency of input usage when facing more intensified competition. However, the transmission and distribution assets from the former SPC were inherited by two transmission companies that dominate the electricity supply of the whole country and do not face direct competition among themselves as they have no overlap in the serviced region. Therefore, we only investigate the impact of the increased competition on the input use of the generation firms after the restructuring. The positive effect on the efficiency of input use from the competition effects could mitigate the negative impact of vertical unbundling on the labor use of generation firms due to the loss of synergy and coordination. Thus, we would expect vertical unbundling to have a less negative impact on the efficiency of labor use of the generation firms that face more intensified competition. Because of the cost transferring channel from the upstream and downstream structure between the generation and transmission sectors, the transmission firms that are located in the regions where the generation sector faces stronger competition would experience a smaller increase in the material expenditure because of the improved efficiency of the upstream suppliers and the increased bargaining power when negotiating with the generation firms. To test our conjecture, we measure the competition intensity in the generation sector using the number of newly entered generation firms during 2003-2007 (post-restructuring) in each city, and then estimate the heterogeneous effects for the subgroups of the firms located in cities where the number of new generation firms are below and above the median, respectively. Columns (5)-(6) of Table 6 show that in the cities where the generation sector faces more intensified competition, the generation firms suffered less efficiency loss of labor use and the transmission firms experienced a smaller increase in material use. We believe the competition effects were not strong enough to offset the negative impacts of vertical unbundling due to the following reasons. First, 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, especially subsides in coal, and therefore are less incentivized to flexibly adjust their resources when facing a more intensified competition, compared with independent local generation firms. Second, 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 their historic ties and more established connection. The long-term contracts signed between state-owned generation and transmission firms also put the generation firms that were separated from SPC in a more favorable position than independent and private generators. 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 independent generation firms. Third, the long-planned price deregulation and competitive wholesale bidding reform associated with the structuring were suspended in 2006 after several unsuccessful trials in some cities because of the power shortage experienced in many regions, profit loss from state-owned firms, and the decentralized authority in inspecting and punishing anti-competitive practices in the electricity industry (Gao and Van Biesebroeck, 2014).

4.4 Heterogeneity

These estimated overall effects may mask economically interesting heterogeneity. We next examine treatment effect heterogeneity across firm size, age and region. We focus on the labor input for the generation sector and material use for the transmission sector, respectively, and explore the heterogeneous effects by conducting subsample regressions according to whether the firm's capital stock and age in 2002 are above or below the median level, and whether the firms are located in western/central region or eastern region in China[9].

The firm heterogeneity results for the generation sector are reported in Panel A of Figure 4. For firms that experienced the vertical unbundling, firms with a larger size suffered a larger increase in labor use than smaller firms, which implies that larger firms enjoyed more benefits from synergy of vertical integration and require more employees after being separated from an integrated company. When examining the European market, Gugler et al. (2017) also finds that the magnitude of economies of integration tends to increase with firm size. Our results also find that the restructuring had a lager impact on labor input for older firms, compared with firms that were more recently established. The older generation firms tended to bear more historical burden of excess

[9] The definition of western, central and eastern regions of China follows the official classification of provinces in China's Statistical Yearbook.

employment and face more technological constraints, and thus were less capable to compete with newly established firms and suffered a larger efficiency loss of the labor input after the restructuring. In terms of geographical regions, vertical unbundling had a larger impact on the labor use for the firms located in western or central regions in China, but no statistically significant difference is found when comparing with the estimated effect for the eastern region.

However, due to the difference in the market structure, the results in the transmission sector reflect a different pattern, as shown in Panel B of Figure 4. We find that the restructuring had a larger impact on the material use for both smaller and younger transmission firms. The transmission sector operates as a natural monopoly, demanding substantial investment in the fixed assets in order to achieve economies of scale. Meanwhile, it generally took several years to accomplish the construction of power grid and transmission lines, and thus older transmission firms tend to have a larger size. Those larger and older transmission firms possess larger market power because of their more important role in serving the local electricity demand, making smaller and younger transmission firms in a less competitive positon when negotiating with the generation firms. In terms of the service region, the impact of the restructuring on material use is notably larger for the transmission firms located in western or central China, and statistically insignificant for the firms in eastern region. This result is consistent with our findings in the generation sector that the restructuring increased the labor use of the generation firms located in the western/central region with a larger magnitude, thus imposing a larger burden of the material use of the downstream transmission firms in the region. Moreover, eastern China experienced a more rapid economic growth during 2003-2007, demanding more and higher quality of power supply to support the larger output in the manufacturing industry. Hence, the demand-driven forces further pushed forward the transmission firms in eastern China to update their power grid and adopt more advanced technologies more promptly to reduce the input costs.

5 Conclusion

This paper investigates the impact of the vertical unbundling restructuring in 2003 on the input use efficiency of both the electricity generation and transmission sectors in China. For the generation sector, we find that the vertical unbundling lowered the labor use efficiency by 14.9 percent but did not have a significant impact on the efficiency of material use. However, the restructuring reduced the material input efficiency by 29.3 percent, but had no significant impact on the labor use efficiency for the transmission sector. The estimated efficiency losses are equivalent to employing 2.5 percent additional workers in the generation sector and 31.9 percent of additional annual expenses on materials in the transmission sector. By exploring the potential mechanisms, we find that the efficiency loss of the labor use in the generation firms was mainly caused by the loss of economies of vertical integration, though the more intensified competition partially offsets the negative effects. By featuring the characteristics of a natural monopoly, the transmission firms that experienced the restructuring did not face stronger competition, but suffered an efficiency loss in the material input because of the increased transaction cost in obtaining the input and the cost transferred from the efficiency loss in labor input of the upstream generation firms. The result is consistent with the finding that the transmission firms located in the cities with more intensified competition in the generation sector suffers a less efficiency loss in the material input. Meanwhile, heterogeneity analysis reveals that the vertical unbundling reform had a larger impact on the labor use of larger and older generation firms, and smaller and younger transmission firms and the transmission firms located in western or central China suffered a larger efficiency loss in material use. By proving the first thorough investigation of the impacts of the vertical unbundling on the entire electricity industry in China, our study provides new evidence to the comparison of the performance between vertical integration and specialization operations in the industries that feature market power and vertical industrial chain, and provides valuable insights to other developing countries that plan to adopt vertical unbundling in the electricity industry.

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Table 1—Summary Statistics, 2002

	Balanced Panel				Balanced Panel with Entropy Balancing			
	Panel A: Generation Sector							
	Treat	Control	Difference	*p*-value	Treat	Control	Difference	*p*-value
Ln(Labor)	6.487	5.618	0.868	0.000	6.487	6.559	-0.072	0.599
	(1.005)	(1.073)			(1.005)	(0.995)		
Ln(Material)	12.205	10.003	2.203	0.000	12.205	12.175	0.030	0.876
	(1.416)	(1.804)			(1.416)	(1.406)		
Ln(K)	13.388	11.272	2.117	0.000	13.388	13.388	0	1
	(1.636)	(1.671)			(1.636)	(1.636)		
Ln(Revenue)	12.833	10.599	2.234	0.000	12.833	12.833	0	1
	(1.283)	(1.716)			(1.283)	(1.283)		
Ln(Wage)	3.354	2.7846	0.570	0.000	3.354	3.354	0	1
	(0.551)	(0.692)			(0.551)	(0.541)		
SOE	0.432	0.578	0.146	0.019	0.432	0.432	0	1
	(0.488)	(0.453)			(0.488)	(0.488)		
Age	20.356	17.081	3.275	0.085	20.356	20.356	0	1
	(15.307)	(13.837)			(15.307)	(15.307)		
Observations	59	641			59	641		
	Panel B: Transmission Sector							
Ln(Labor)	5.839	5.677	0.162	0.044	5.839	5.948	-0.109	0.264
	(0.845)	(0.991)			(0.845)	(1.082)		
Ln(Material)	9.604	9.234	0.371	0.003	9.604	9.753	-0.151	0.349
	(1.361)	(1.382)			(1.361)	(1.787)		
Ln(K)	10.671	10.387	0.284	0.022	10.671	10.671	0	0
	(1.343)	(1.314)			(1.343)	(1.342)		
Ln(Revenue)	11.078	10.388	0.690	0.000	11.078	11.077	0.001	0.993
	(1.295)	(1.151)			(1.295)	(1.296)		
Ln(Wage)	2.695	2.576	0.119	0.009	2.695	2.695	0	1
	(0.501)	(0.422)			(0.501)	(0.501)		
SOE	0.902	0.883	0.019	0.428	0.902	0.902	0	1
	(0.259)	(0.269)			(0.259)	(0.259)		
Age	30.141	22.390	7.751	0.000	30.141	30.140	0.001	0.999
	(14.198)	(14.219)			(14.198)	(14.197)		
Observations	694	141			694	141		

Notes: This table reports the summary statistics for the balanced panel of generation and transmission firms in 2002. Ln denotes the natural logarithmic operation. Labor measures the total number of employees of each firm. Material is the firm's intermediate input expenditure in value terms, not in physical quantities. K is the capital stock for each firm, calculated in perpetual inventory method. Revenue is total output values in each firm. Wage is defined as the total labor compensation, including wage and nonwage expenditures, over the total employees. SOE is the ratio of the state-owned investments for each firm. Age counts the number of years each firm has been in operation. All the covariates, Ln(K), Ln(Revenue), Ln(Wage), SOE and Age, are then weighted by the Entropy Balancing to alleviate sample selection. In Panel A, the treatment group consists of firms belonging to the Big Five generation companies that experienced the vertical unbundling, while the control group includes the firms that remained the original organizational structure. In Panel B, the treatment group represents the transmission firms that belonged to the two transmission companies separated from State Power Company (SPC), and the control group consists of the transmission firms that remain vertically integrated. Parentheses contain standard deviations.

Table 2—Input Demand Effects of the Vertical Unbundling in the Generation Sector

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
				Panel A: Ln(Labor)			
Unb × Post03	0.171***	0.167***	0.167**	0.140***	0.156***	0.149***	0.162***
	(0.050)	(0.053)	(0.067)	(0.049)	(0.051)	(0.048)	(0.054)
Ln(Revenue)	0.206***	0.187***	0.177***	0.163***	0.166***	0.166***	0.191***
	(0.023)	(0.022)	(0.020)	(0.018)	(0.019)	(0.020)	(0.045)
Ln(Wage)	-0.218***	-0.228***	-0.214***	-0.191***	-0.191***	-0.191***	-0.159***
	(0.040)	(0.041)	(0.029)	(0.024)	(0.023)	(0.023)	(0.042)
Observations	5,596	5,504	5,504	5,504	5,504	5,504	5,504
R^2_Adj	0.951	0.952	0.953	0.959	0.960	0.961	0.951
				Panel B: Ln(Material)			
Unb × Post03	0.055	0.057	0.103*	0.090	0.102	0.048	0.009
	(0.051)	(0.051)	(0.059)	(0.066)	(0.071)	(0.064)	(0.064)
Ln(Revenue)	0.886***	0.877***	0.878***	0.875***	0.879***	0.855***	0.762***
	(0.030)	(0.031)	(0.032)	(0.032)	(0.031)	(0.031)	(0.047)
Observations	5,593	5,502	5,502	5,502	5,502	5,502	5,502
R^2_Adj	0.958	0.959	0.959	0.960	0.961	0.963	0.961
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Other Covariates	No	Yes	Yes	Yes	Yes	Yes	Yes
Firm Size Effects	No	No	Yes	Yes	Yes	Yes	Yes
Price Controls	No	No	No	Yes	Yes	Yes	Yes
Power-type-Year FE	No	No	No	No	Yes	Yes	Yes
Province-Year FE	No	No	No	No	No	Yes	Yes
Entropy Balancing	No	No	No	No	No	No	Yes

Notes: The time period is 2000-2007. In Panel A, the dependent variable is the natural logarithm of the total number of employees in each firm, while in panel B, it is the logarithm of the intermediate input expenditures for each firm. Unb is an indicator variable that equals one for firms that were affiliated with the Big Five generation companies and experienced the vertical unbundling, and zero for firms that remained their original organizational structure. Post03 equals zero for 2000-2002 and one for 2003-2007. Ln(Revenue) is the logarithm of total output values in each firm. Ln(Wage) is the logarithm of the sum of wage and nonwage expenditures per employee for each firm. Other covariates include Ln(K), SOE and Age. To control for the possible discrepancy effects on input demand stemmed from firm size differences between the control and treatment groups over time, we include firm size effects, which are firm's capital stock interacted with time dummies over 2000-2007. Capital stock, SOE and Age in each firm are interacted with province dummies to form price controls to control for the firm-specific deviations from average prices of input and output as in Gao and Van Biesebroeck (2014). Power type includes fossil-fueled, thermal, and others. In column (7), the samples in the regression are weighted by Entropy Balancing method. Standard Errors are clustered at the firm level 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—Input Demand Effects of the Vertical Unbundling in the Transmission Sector

			Panel A: Ln(Labor)			
	(1)	(2)	(3)	(4)	(5)	(6)
Unb × Post03	0.041*	0.035	0.037	0.053**	0.035	0.043
	(0.024)	(0.023)	(0.023)	(0.023)	(0.036)	(0.036)
Ln(Revenue)	0.261***	0.249***	0.247***	0.211***	0.178***	0.158***
	(0.032)	(0.032)	(0.031)	(0.023)	(0.023)	(0.035)
Ln(Wage)	-0.304***	-0.305***	-0.304***	-0.300***	-0.308***	-0.284***
	(0.024)	(0.024)	(0.024)	(0.022)	(0.022)	(0.062)
Observations	6,674	6,648	6,648	6,648	6,648	6,648
R^2_Adj	0.948	0.948	0.948	0.951	0.954	0.961
			Panel B: Ln(Material)			
Unb × Post03	0.326***	0.328***	0.326***	0.252***	0.295***	0.293***
	(0.076)	(0.077)	(0.077)	(0.075)	(0.086)	(0.086)
Ln(Revenue)	0.842***	0.832***	0.830***	0.830***	0.780***	1.038***
	(0.055)	(0.055)	(0.055)	(0.055)	(0.057)	(0.123)
Observations	6,670	6,645	6,645	6,645	6,645	6,645
R^2_Adj	0.826	0.827	0.827	0.835	0.868	0.881
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Other Covariates	No	Yes	Yes	Yes	Yes	Yes
Firm Size Effect	No	No	Yes	Yes	Yes	Yes
Price Controls	No	No	No	Yes	Yes	Yes
Province-Year FE	No	No	No	No	Yes	Yes
Entropy Balancing	No	No	No	No	No	Yes

Notes: The time period is 2000-2007. In Panel A, the dependent variable is natural logarithm of the total number of employees in each firm, while in panel B, it is the logarithm of the intermediate input expenditures for each firm. Unb is an indicator variable that equals one for firms that belonged to the two transmission companies separated from SPC and experienced the vertical unbundling, and zero for firms that remained original organizational structure. Post03 equals zero for 2000-2002 and one for 2003-2007. Ln(Revenue) is the logarithm of total output values in each firm. Ln(Wage) is the logarithm of the sum of wage and nonwage expenditures per employee for each firm. Other covariates include Ln(K), SOE and Age. To control for the possible discrepancy effects on input demand stemmed from firm size differences between the control and treatment groups over time, we include firm size effects, which are firm's capital stock interacted with time dummies over 2000-2007**.** Capital stock, SOE and Age in each firm are interacted with province dummies to form price controls to control for firm-specific deviations from average prices of input and output as in Gao and Van Biesebroeck (2014). In column (7), the samples in the regression are weighted by Entropy Balancing method. Standard Errors are clustered at the firm level 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 4—Dynamic Effects of the Vertical Unbundling on Input Demand

	Generation Sector		Transmission Sector	
	(1)	(2)	(3)	(4)
	Ln(Labor)	Ln(Material)	Ln(Labor)	Ln(Material)
Unb × Year 2000	-0.121	0.003	0.049	0.051
	(0.148)	(0.076)	(0.038)	(0.093)
Unb × Year 2001	0.029	0.044	-0.012	-0.078
	(0.042)	(0.083)	(0.037)	(0.073)
Unb × Year 2003	0.064**	0.125	-0.008	-0.087
	(0.028)	(0.091)	(0.022)	(0.066)
Unb × Year 2004	0.130**	0.030	0.023	0.312***
	(0.051)	(0.079)	(0.035)	(0.120)
Unb × Year 2005	0.128***	0.068	0.064	0.350***
	(0.046)	(0.080)	(0.040)	(0.120)
Unb × Year 2006	0.155***	0.060	0.058	0.531***
	(0.044)	(0.088)	(0.041)	(0.137)
Unb × Year 2007	0.168***	0.027	0.108**	0.366**
	(0.056)	(0.095)	(0.048)	(0.143)
Ln(Revenue)	0.167***	0.855***	0.176***	0.775***
	(0.020)	(0.031)	(0.023)	(0.056)
Ln(Wage)	-0.191***		-0.308***	
	(0.023)		(0.022)	
Firm FE	Yes	Yes	Yes	Yes
Other Covariates	Yes	Yes	Yes	Yes
Firm Size Effect	Yes	Yes	Yes	Yes
Price Controls	Yes	Yes	Yes	Yes
Power-type-Year FE	Yes	Yes	Yes	Yes
Province-Year FE	Yes	Yes	Yes	Yes
Observations	5,504	5,502	6,648	6,645
R^2_Adj	0.961	0.963	0.955	0.868

Notes: Table 4 reports estimates from the fully dynamic baseline model with the following outcomes: natural logarithm of the total number of employees (columns 1 and 3) and natural logarithm of the intermediate input expenditures (columns 2 and 4). As for generation sector, Unb is an indicator variable that equals one for firms that were affiliated with the Big Five generation companies and experienced the vertical unbundling, and zero for firms that remained the original organizational structure. Similarly, for transmission sector, Unb is an indicator variable that equals one for firms that belonged to two transmission companies separated from SPC, and experienced the vertical unbundling, and zero for firms that remained integrated. All the other control variables are defined in the same way as in Table 2 and Table 3. Standard Errors are clustered at the firm level 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—Robustness Checks

Panel A: Generation Sector								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Ln(Labor)	Ln(Labor)	Ln(Labor)	Ln(Labor)	Ln(Labor)	Ln(Labor)	Ln(Labor)	Ln(Labor)
	2000-2002	Exclude IM	<= 100 km	<= 200 km	<= 300 km	CEM	CEM k2k	PSM
Unb × Post01	0.129							
	(0.153)							
Unb × Post03		0.153***	0.126***	0.148***	0.147***	0.132**	0.129**	0.173***
		(0.048)	(0.042)	(0.046)	(0.047)	(0.067)	(0.063)	(0.047)
Ln(Revenue)	0.153***	0.166***	0.180***	0.168***	0.167***	0.188***	0.168***	0.177***
	(0.046)	(0.020)	(0.028)	(0.020)	(0.020)	(0.053)	(0.058)	(0.024)
Ln(Wage)	-0.213***	-0.191***	-0.198***	-0.176***	-0.184***	-0.112***	-0.119**	-0.166***
	(0.054)	(0.023)	(0.029)	(0.023)	(0.023)	(0.039)	(0.052)	(0.026)
Observations	2012	5464	3390	5118	5363	1913	876	3999
R^2_Adj	0.969	0.961	0.957	0.960	0.960	0.937	0.953	0.957
Panel B: Transmission Sector								
	Ln(Material)	Ln(Material)	Ln(Material)	Ln(Material)	Ln(Material)	Ln(Material)	Ln(Material)	Ln(Material)
	2000-2002	Exclude IM	<= 100 km	<= 200 km	<= 300 km	CEM	CEM k2k	PSM
Unb × Post01	-0.095							
	(0.087)							
Unb × Post03		0.294***	0.260***	0.304***	0.301***	0.240**	0.242**	0.298***
		(0.086)	(0.089)	(0.087)	(0.087)	(0.093)	(0.120)	(0.088)
Ln(Revenue)	0.465***	0.818***	0.905***	0.792***	0.780***	0.832***	0.864***	0.801***
	(0.133)	(0.064)	(0.073)	(0.062)	(0.060)	(0.065)	(0.080)	(0.058)
Observations	2471	6237	4646	6135	6437	5406	2177	6449
R^2_Adj	0.908	0.863	0.861	0.861	0.866	0.827	0.822	0.850
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Other Covariates	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm Size Effect	Yes	Yes	Yes	Yes	Yes	No	No	No
Price Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Power-type-Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Province-Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

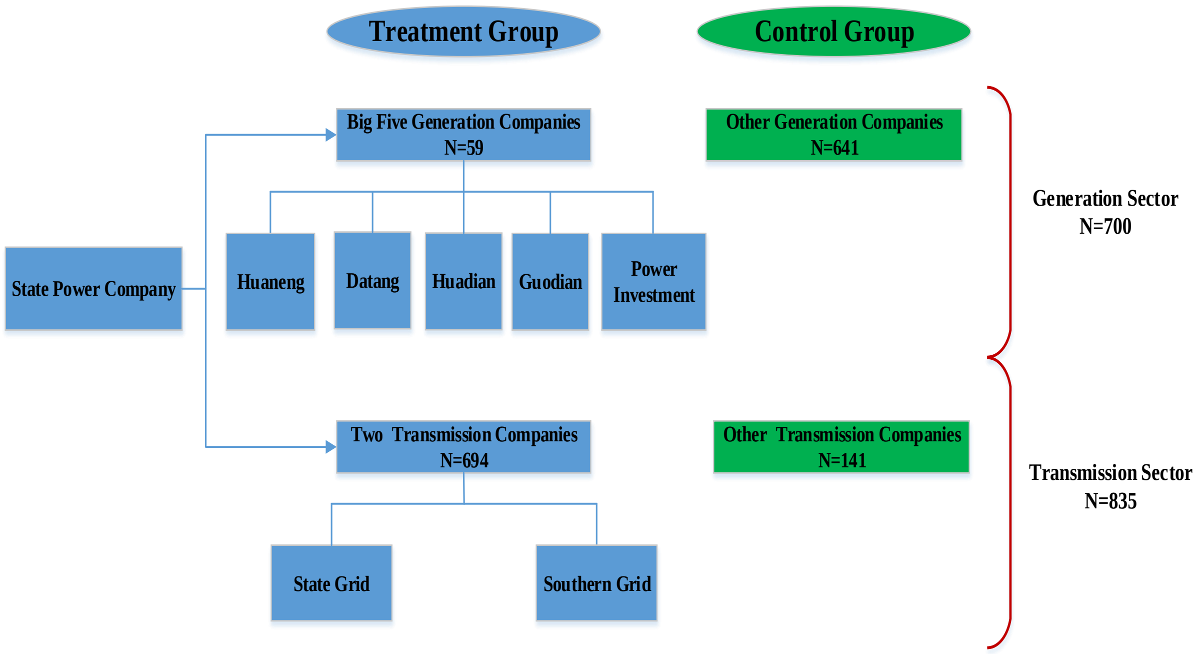
Notes: Column 1 assumes that the restructuring reform occurred in 2001 instead of 2003, and focused on the observations between 2000 and 2002 only. Columns 2 excludes samples from the Inner Mongolia Autonomous Region, which implemented two rounds of the vertical unbundling in 2004 and 2006, respectively. Columns 3-5 restrict firms in the control group to be less than 100 km, 200 km and 300 km away from the nearest firm in the treatment group, respectively. Column 6 matches the firm's fundamental characteristics, i.e. Ln(Revenue), Ln(Wage) and Ln(K) by Coarsened Exact Matching (CEM). In column 7, all the covariates are balanced in 2002 by one-by-one CEM assuring the same number of treated and control by randomly dropping observations. In column 8, all the covariates are balanced in 2002 by propensity score matching (PSM), specifically the nearest neighbor matching with logit model. The dependent variable is the natural logarithm of the total number of employees for each firm in Panel A, and that of the intermediate input expenditures of each firm in Panel B, respectively. All the other control variables are defined in the same way as in Table 2 and Table 3. Standard Errors are clustered at the firm level 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—Mechanisms

	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: Generation Sector						
	Distance				# of New Firms	
	(1)	(2)	(3)	(4)	(5)	(6)
	Ln(Labor) Below median	Ln(Labor) Above median	Ln(Material) Below median	Ln(Material) Above median	Ln(Labor) Below median	Ln(Labor) Above median
Unb × Post03	0.193***	0.031	0.062	0.088	0.195**	0.100**
	(0.056)	(0.062)	(0.065)	(0.143)	(0.079)	(0.044)
Ln(Revenue)	0.178***	0.155***	0.832***	0.879***	0.185***	0.150***
	(0.026)	(0.030)	(0.038)	(0.046)	(0.033)	(0.024)
Ln(Wage)	-0.176***	-0.195***			-0.234***	-0.147***
	(0.027)	(0.039)			(0.038)	(0.030)
Observations	2,707	2,797	2,706	2,796	2,707	2,795
R^2_Adj	0.960	0.964	0.966	0.953	0.953	0.965
Panel B: Transmission Sector						
	Distance		Labor Growth in Generation		# of New Firms	
	Ln(Labor) Below median	Ln(Labor) Above median	Ln(Material) Below median	Ln(Material) Above median	Ln(Material) Below median	Ln(Material) Above median
Unb × Post03	0.012	0.037	0.159	0.394***	0.345***	0.227*
	(0.065)	(0.045)	(0.129)	(0.140)	(0.124)	(0.122)
Ln(Revenue)	0.178***	0.177***	0.918***	0.827***	0.648***	0.861***
	(0.035)	(0.030)	(0.098)	(0.085)	(0.076)	(0.076)
Ln(Wage)	-0.293***	-0.308***				
	(0.030)	(0.034)				
Observations	3,107	3,268	2,706	2,769	3,141	3,464
R^2_Adj	0.961	0.948	0.852	0.899	0.860	0.876
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Other Covariates	Yes	Yes	Yes	Yes	Yes	Yes
Firm Size Effect	Yes	Yes	Yes	Yes	Yes	Yes
Price Controls	Yes	Yes	Yes	Yes	Yes	Yes
Power-type-Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Province-Year FE	Yes	Yes	Yes	Yes	Yes	Yes

Notes: This table reports subsample regressions based on the specifications of column 6 in Table 2 and Column 5 in Table 3. The time period is 2000-2007. Distance is defined as the median distance between generation and transmission firms in the same city in 2002. # of New Firms denotes that the total number of newly entered generation firms during 2003-2007 in each city. Labor growth in generation is represented by the median growth rate of employment of the generation firms between 2000-2002 and 2003-2007 in each city. In Panel A, we divide the power firms into two groups by whether they were located in the cities where the distance and number of newly entered firms were above or below the median values among all cities in 2002. Similarly, the transmission firms are grouped into subsamples according to whether they belong to the cities were the distance, number of newly entered firms and growth rate of employment in the generation sector where above or below the median level. Both the dependent and independent variables are defined in the same way as in Table 2 and Table 3. Standard Errors are clustered at the firm level 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.

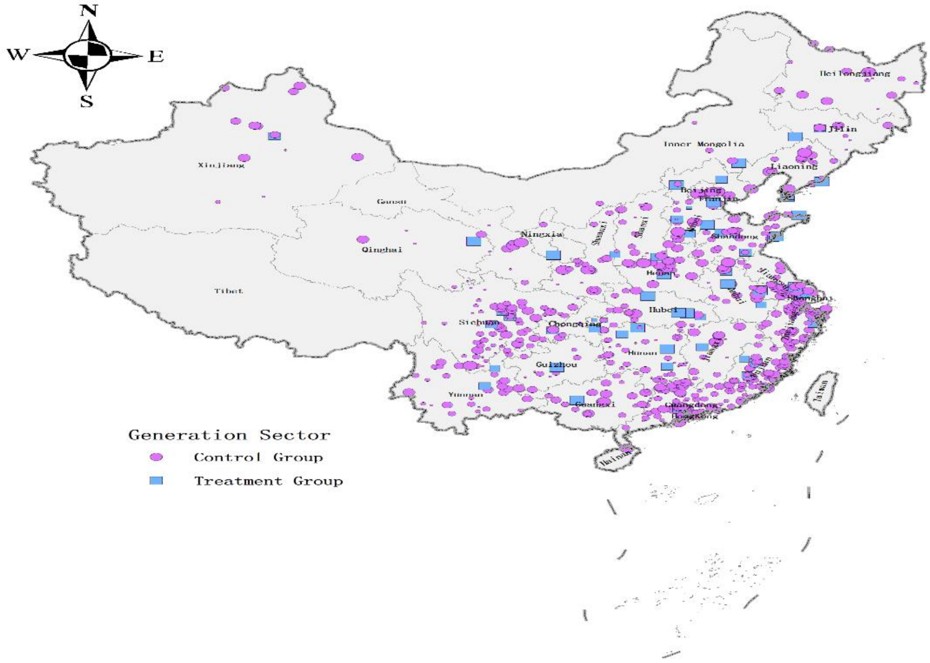
Figure 1—Vertical Unbundling and Definition of Control and Treatment Groups



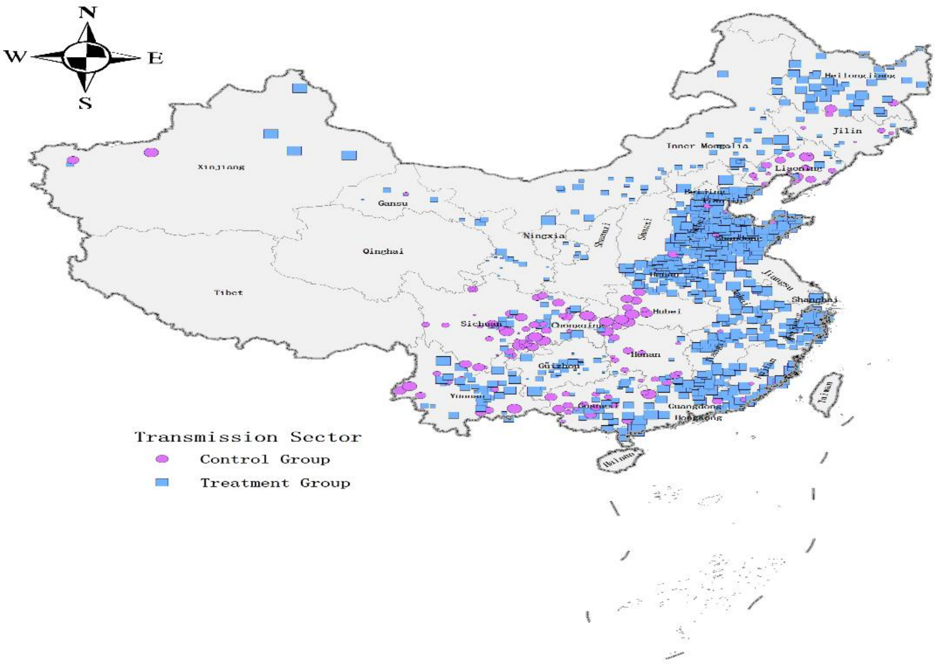
Notes: The figure shows the electricity firms that are included in our analysis, both for the generation and transmission sectors. In 2003, the former State Power Company (SPC) was restructured with its generation assets reallocated to five generation companies (Huaneng, Datang, Huadian, Guodian and Power Investment), and its transmission and distribution assets allocated to two transmission companies (State Grid and Southern Grid). Each of the companies has its own subsidiaries. The remaining generation and transmission companies that did not belong to SPC remained their organizational form after the restructuring.

Figure 2—Geographical Distribution of Treated and Control Firms

Panel A: Generation Sector



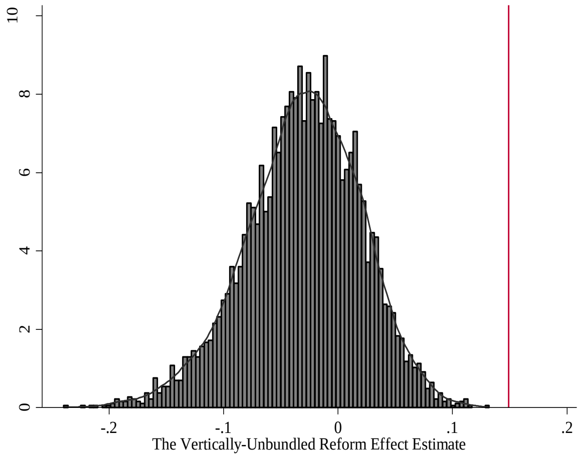
Panel B: Transmission Sector



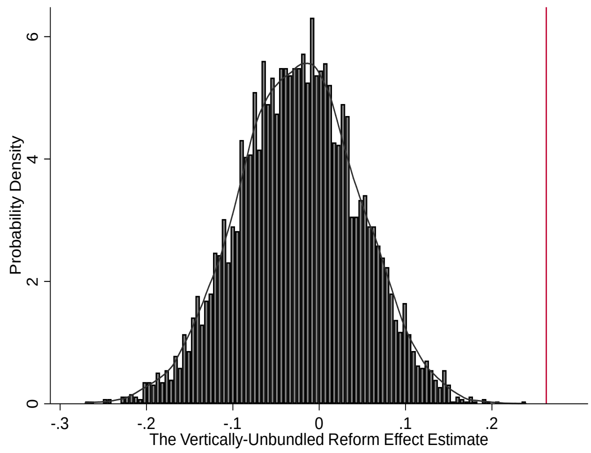
Notes: The map plots the location of the firms belonging to the balanced panel reported in Table 1. The blue boxes represent firms in the treatment group, which are the firms experienced the vertical unbundling in the generation and transmission sectors. The purple dots represent firms in the control group, which remained the original organization form after the reform. The size of the boxes and dots represent the relative size of each firm, which are weighted by the natural logarithm of the natural logarithm of their capital stock.

Figure 3— Distribution of Estimated Coefficients of Falsification Test

Panel A: Ln(Labor), Generation Sector



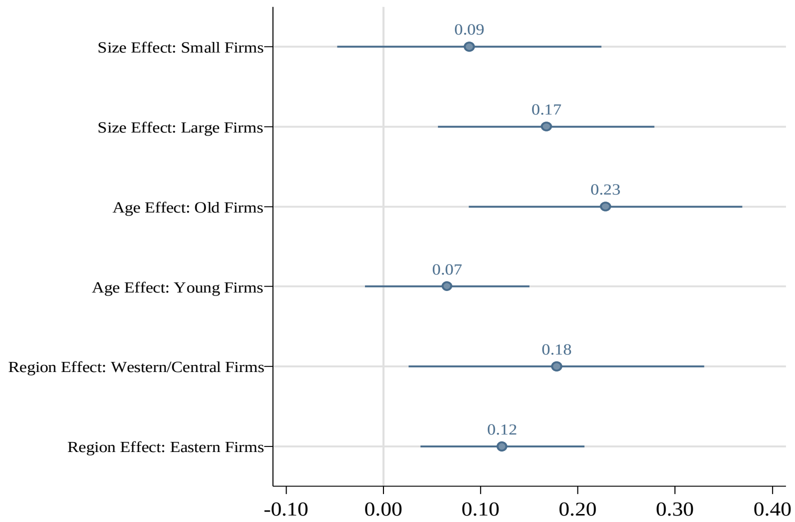
Panel B: Ln(Material), Transmission Sector



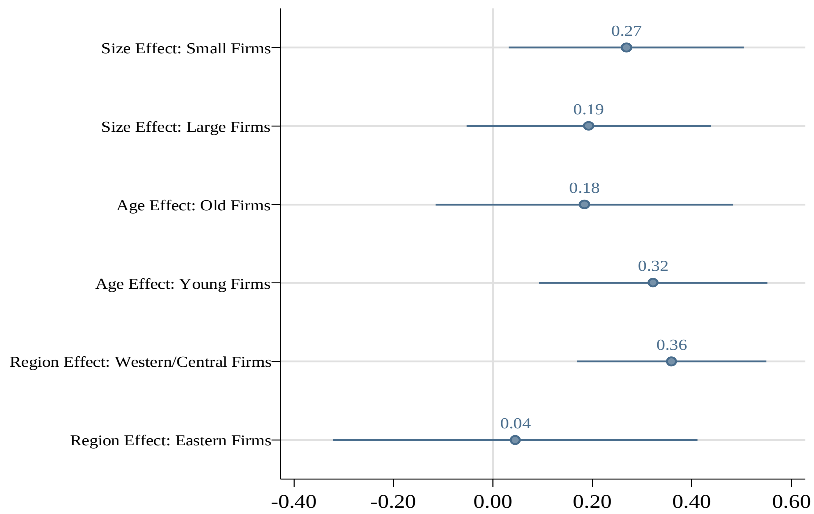
Notes: In panel A, the dependent variable is the natural logarithm of the total number of employees. The figure shows the distribution density of the estimated coefficients is from 5000 simulations randomly assigning the vertically-unbundled status to firms in generation sector. The vertical line presents the result of column (6) in Panel A of Table 2. In panel B, the dependent variable is the natural logarithm of the intermediate input expenditures. The figure shows the distribution density of the estimated coefficients is from 5000 simulations randomly assigning the vertically-unbundled status to firms in transmission sector. The vertical line presents the result of column (5) in Panel B of Table 3.

Figure 4—Heterogeneous Treatment Effects

Panel A: Ln(Labor), Generation Sector



Panel B: Ln(Material), Transmission Sector



Notes: The table reports the subsample regressions based on the specifications of columns 6 in Table 2 and column 5 in Table 3. The firms are divided into different groups according to whether their capital stock and age are above or below the median value of all firms in the sample, and whether they are located in western/central region or eastern region in China. For each category, we report the differential treatment effect along with 95 percent. Standard Errors are clustered at the firm level.