Effects of Deregulation and Vertical Unbundling on the Performance of China's Electricity Generation Sector*

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Abstract

The 2002 restructuring of the Chinese electricity sector reshaped the market structure by vertically unbundling the dominant integrated firm and put forward a road map towards wholesale price liberalization. We estimate factor demands to study whether these reforms boosted productivity in the generation segment of the industry. Controlling explicitly for sources of price-heterogeneity across firms and the endogeneity of unobserved productivity effects, we find the reform to be associated with a reduction in labor input and material use of 6 and 4 percent, respectively. This effect only appears two years after the reforms and is robust to alternative ways of identifying restructured firms.

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1 Introduction

Launched in 2002, the latest reform of China's electricity industry was intended to bring genuine competition to the generation segment. It consisted of two parts: it reshaped the market structure by vertically unbundling the dominant integrated firm and it put forward a road map towards wholesale price liberalization (OECD, 2010). We study whether these reforms improved the efficiency of electricity generation.

This is particularly important for China, where the manufacturing sector accounts for an unusually large share of the economy and requires reliable and ever increasing amounts of electric power. Many provinces have suffered occasional brownouts in the last decade when generators with generation costs surpassing the regulated price refused to produce electricity. Total electricity demand continues to grow and new capacity is constantly added. Given that China is the world's largest emitter of greenhouse gasses—almost half of its total CO2 emissions come from electricity generation (World Bank, 2012)—it is even an issue of global importance.

The impact of the reforms on operational efficiency could work through several channels. Competition intensified as more evenly matched firms jostled for market share in anticipation of a fully liberalized market. Firms needed vast amounts of capital to finance capacity additions and could no longer afford to waste resources on inefficient operations. In line with the far-reaching restructuring of firms in other parts of the economy, the reforms signaled that exit became a distinct possibility for firms used to a soft budget constraint. It also put in place a clear end game for the sector, including a path towards genuine price competition and all firms becoming residual claimants on their efficiency gains.[1]

We build on the model of Fabrizio et al. (2007) to estimate efficiency gains, but incorporate a number of features unique to the Chinese situation. We advance the existing literate, in particular the work of Du et al. (2008), on three counts: (i) our data includes the post-reform period and is more comprehensive, (ii) we control explicitly for firm-heterogeneity in coal and electricity prices, and (iii) we verify the robustness of the estimates to alternative ways of defining deregulated firms. We briefly elaborate on each contribution.

First, we observe the universe of all Chinese fossil fuel-fired electricity generation companies from 1998 to 2007. We can follow firms over time which allows the

[1] At the end of 2005 the proposed full liberalization of the wholesale electricity price, in particular competitive bidding into regional power pools, was put on hold. Because the preparations between 2002 and 2005 had proceeded as planned and the government repeatedly indicated that price liberalization was only postponed not canceled, firms still had incentives to restructure in preparation of further liberalization.

inclusion of fixed effects to capture the primary dimension of unobserved heterogeneity. Instrumental variables are only needed to control for the remaining sources of endogeneity and we introduce outside information to avoid relying solely on timing assumptions. As we observe the industry in several years following the reforms, we can show that it took several years for the effects to materialize fully and that the efficiency levels of state-owned and private firms no longer differ for new entrants. Both effects are not unexpected in a capital intensive sector.

Second, the continued existence of regulated prices, not only for electricity but also for coal, the primary input, complicates the productivity growth calculations (Wang, 2007). The system of regulated generation tariffs is fairly constant over time and firm dummies will absorb most of the differences in levels. Dual track pricing in the coal market is more troubling as the importance of subsidized coal for benefitting firms has shrunk over time. The problem of missing price data is addressed by relying on institutional details of the electricity and coal markets that suggest firm-age, size, location, and legal ownership structure are good predictors for the firm-level price differentials.[2]

Third, identifying the firms most directly affected by the reforms is not without ambiguity. Many firms in China have hybrid forms of ownership and even state-owned firms sometimes enjoy large autonomy. Du et al. (2008) focused on plants previously owned by the State Power Company (SPC), the formerly dominant integrated firm. It is likely, though, that some of its subsidiaries that had already transformed to listed shareholder companies or that already had a diversified ownership structure in 2002 were only indirectly affected. At the same time, attempts to deregulate output and input prices had similar effects on state-owned companies that were not SPC subsidiaries. Prior to the reforms they also were likely to have preferential access to coal allotments or influence over regulated electricity prices. Following Zhang et al. (2001), we use the legal ownership category in 2002 to identify 'restructured' firms in the benchmark specification and we perform sensitivity checks using alternative definitions.[3]

The estimates suggest a positive impact of the reforms on production efficiency. After 2002, factor demands decline more rapidly for formerly state-owned firms, but it takes at least two years for a significant gap to open up with private and foreign-owned

[2]The electricity tariff structure is somewhat inscrutable, but prices are fixed at a regional level and stable over time (Wang, 2007). The price of 'electricity coal' is still managed and kept 30-40 RMB per tonne below the market price, which applies to coal used in other activities than electricity generation and has largely been deregulated. The underpricing creates scarcity and large state-owned generators have preferential access to the cheapest coal from state-owned mines (Mathys, 2011).

[3]Furthermore, we verified the results using a matching technique from the treatment evaluation literature to control for the possibility of non-random treatment of firms.

firms. Our preferred estimates suggest that restructured fossil fuel-fired electricity generation firms eventually reduce their labor input by 6 percent and material input (fuel and non-fuel combined) by 4 percent relative to firms only indirectly affected by the reforms. Employment reductions are broadly based, but proportionally stronger for small firms, while the reduction in material use is concentrated entirely in large firms. Effects for both input factors are stronger for older firms than for younger. In the post reform period, we find no more significant productivity differences between new entrants that are state-owned or private.

Deregulation of the electricity sector is an ongoing process with effects on many dimensions of industry competition and firm operations. Joskow (2008) provides an overview of experiences in several OECD countries. Newbery and Pollitt (1997) conduct a cost-benefit analysis of the reforms in the United Kingdom taking into account generator efficiency gains, but also the effects on emissions, pricing, and investment incentives. The impact of deregulation on prices has been contentious, with Hattori and Tsutsui (2004) finding a tempering effect comparing across countries, while Borenstein, Bushnell, and Wolak (2002) and Joskow and Kahn (2002) identifying the abuse of market power as the main culprit for the failure of the California regulatory regime in the summer of 2000. Knittel (2002) reports evidence of rising efficiency at generation plants associated with the diffusion of incentive regulation.

The main purpose of the 2002 reforms in China was to improve production efficiency of electricity generation. Several studies have attempted to quantify ex-post operating efficiency gains from similar restructuring episodes in other countries. Newbery and Pollitt (1997) find that the move from a state-owned monopoly to a privatized, competitive generation market in the United Kingdom was accompanied by a significant reduction in employment. This represents both restructuring and privatization effects. Two studies exploit the differential timing of reforms across countries to look for efficiency gains following deregulation. Steiner (2000) studies OECD countries and finds that while changes in legal rules only translate slowly into changes in conduct, unbundling of generation and introducing private ownership has a positive and significant impact on most performance measures. Zhang, Parker, and Kirkpatrick (2008) study 51 developing countries and find favorable effects on service penetration, capacity expansion, labor efficiency, and prices for industrial users.

Hiebert (2002) provides the first econometric plant-level evidence studying the effect of U.S. restructuring over the 1988–1997 period using a stochastic frontier production function. He finds a substantial improvement in generation plant efficiency for coal plants in states that restructured in or before 1996, but no effect for gas-fired plants in the same states nor for policies enacted in 1997. More recently, Fabrizio, Rose, and Wolfram (2007) take endogeneity of input choices more seriously and es-

timate productivity using the control function approach of Olley and Pakes (1996).[4] Their difference-in-differences method to measure the effect of regulatory restructuring on U.S. electricity generation efficiency suggests that labor and non-fuel efficiency of investor-owned utilities in the states that passed restructuring legislation increased by 3 to 5 percent relative to comparable firms in non-restructuring states, and by 6 to 12 percent relative to municipal and federal plants insulated from restructuring incentives. They find little improvement in fuel efficiency.[5]

A final important point of comparison is Du, Mao, and Shi (2008), who evaluate the combined effect of reforms in 1997 and 2002 on the production efficiency of China's electricity generation industry. They closely follow the estimation approach in Fabrizio et al. (2007) and find large efficiency gains of 29 percent in labor input and 35 percent in non-fuel materials for the plants divested from the former Ministry of Electricity Power (MEP) or the State Power Company (SPC) relative to other firms, but no evidence of greater efficiency in fuel use. These effects are cumulative over a nine year period between two census years (1995 and 2004) and imply 2.9 and 3.4 percent annual efficiency gains. As they only observe two cross sections of firms, they cannot control for unobserved firm differences.

The remainder of the paper is organized as follows. Section 2 reviews the electricity reforms in China. Section 3 presents the empirical model and estimation strategy. Section 4 describes the data and provides summary statistics. Section 5 presents the results with robustness checks and sensitivity analysis. Section 6 concludes.

2 Electricity sector restructuring in theory and in practice

Historically, the electricity sector in China was even more than in other countries treated like a natural monopoly. The central government determined prices and quantities for all final electricity users as well as for coal inputs, and it had the final say in all investment decisions. To cope with rapidly expanding demand and frequent brownouts at the start of China's reform period, a gradual process of deregulation started in 1985. New objectives were introduced in subsequent steps: attract private investment, separate the administrative authority from the business operations,

[4] They stress that shocks to input productivity may induce firms to adjust targeted output. Failing to recognize this leads to an upward bias in the estimated efficiency effects by a factor of almost two in some cases.

[5] Bushnell and Wolfram (2005) focus specifically on the effect of divestitures on fuel efficiency. They find a 2% gain for divested plants, but a similar efficiency gain for plants that remained under utility ownership but now faced incentive regulation. They conclude that changes in incentives rather than ownership were the main drivers of fuel efficiency improvement.

and vertically unbundle generation and transmission to introduce competition in the wholesale market.

To relieve lack of capital and power shortages—excess demand in 1985 amounted to 450-500 TWh or nearly 12% of annual generation (Wang, 2007)—the government enacted the policy of "Temporary Provision on Promoting Fund-Raising for Investment in the Electricity Sector and Implementing Different Electricity Tariffs." It allowed for the first time investment in electricity generation from local governments, domestic enterprises, and even foreign companies for units above a minimum scale. By the end of the 1990s, more than half of all electricity was generated by non-state-owned units (Du et al., 2008).[6]

As the transmission lines and distribution grid were still owned by the Ministry of Electricity Power (MEP), the new independent power producers (IPPs) provided electricity at wholesale tariffs set by the government. State-owned plants continued to sell at lower 'plan' prices. The independent generation tariffs were determined according to rate-of-return regulation principles also used in Western countries.[7] They were reset every year based on accounting cost information, but varied also by type of company and with the origin of the capital. Tariffs differed greatly across plants, even within the same firm and sometimes even across generation units within a single plant. Large price differentials persisted over time.

Following these initial reforms, electricity tariffs set by the government increased rapidly. The next stage of deregulation occurred in 1997 when the MEP was split up into two bodies. A new public utility, the State Power Company (SPC), took over all state-owned electricity assets, including generation plants, transmission, and distribution grids. The State Economic and Trade Committee became the new regulator and took over administrative and decision-making functions. One of its immediate actions was to slow down the increase in electricity prices.

In 2002, the next and thus far the last phase of reforms had as primary objective the introduction of real competition in the generation sector. It transformed the structure of the industry by dismantling the SPC and it established an independent regulator that was to develop competitive wholesale and retail markets with liberalized pricing (in five power-regions).

The SPC's generation and transmission assets were divested into five generation and two transmission companies.[8] The generation companies were created such that

[6]'State-owned' is used to indicate ownership by the central government, not local or provincial levels of government.

[7]The objective was to recover investments within a fixed period, generally within 10 years.

[8]The five generation companies are China Huaneng Corporation, China Datang Corporation, China Huadian Corporation, China Guodian Corporation and China Power Investment Corporation,

none had more than 20% market share in any of the new power-regions. The divesture decentralized operations considerably, making possible the celebrated Chinese practice of local experimentation with regulation and reforms. The transmission companies were forced to divest all their generation assets, except for hydro pump-storage capacity, to limit conflicts of interest and improve efficient dispatching of generation units.

The new independent regulatory agency, the State Electricity Regulatory Commission (SERC), was created to supervise and establish a legal framework for the electricity market (Pittman and Zhang, 2008). It was in charge of technical and environmental standards for the industry and could investigate anti-competitive behavior. Most importantly, it was to become the main source of strategy and proposals to establish a market-oriented pricing mechanism for electricity.

Five competitive regional wholesale electricity markets were scheduled to be established by the end of 2005 or early 2006 (Xu and Chen, 2006). Eventually. generators were expected to bid into these regional wholesale power pools and their bids would establish grid-accessing priority.[9] This arrangement would benefit more efficient generators and encourage all firms to improve their productivity.

There are several mechanisms for these reforms to influence the operational efficiency of generators.

First, it unambiguously strengthened competition. Total generation capacity of the former SPC only accounted for 40% of the total and competition with IPPs was already important in many regions, but now there was no dominant company anywhere. Many of the previously spun-off subsidiaries of the SPC, some had even transformed into listed shareholder companies, took the divestiture as a clear signal that they should go their own way and compete more aggressively. Now that firms were more evenly matched, it started a process of firms competing more directly for market share.

Second, simultaneous with the electricity sector reform, the government announced a stop to its policy of guiding coal prices and allowed a market to develop. Coal prices immediately rose and the government was reluctant to allow these cost increases to be reflected into electricity generation tariffs. Given that almost 80% of electricity is generated from coal, this impacted the financial health of all generators and in 2004 a formula was launched to pass 70% of coal price increases through to the grid.[10] Incumbent state-owned generators often continued to have access to subsi-

and the two transmission companies are State Grid Company and China Southern Grid Company.

[9]The New Electricity Trading Arrangement in the U.K. was a comparable mechanism (Wang, 2007); many other countries established similar regional power pools at the wholesale level.

[10]The actual implementation was rather more complicated and involved many deviations. Sub-

dized coal under the old 'plan' prices, but those allotments were fixed in absolute volumes and became gradually less important. Rising input prices provided strong incentives to conserve coal and operate more efficiently. State-owned generators that only recently had become residual claimants on their own profits, still had a lot of scope for efficiency enhancements. Subsequently, explicit policy objectives to lower CO2 emissions in light of China's increased contribution to global warming provided further incentives to increase efficiency.

Third, the developments in the manufacturing sector, where the fraction of the workforce employed by state-owned enterprises was reduced by approximately three quarters sometimes even through bankruptcy, clearly signalled that inefficient and loss-making firms would not be tolerated anymore. By the end of the 1990s, SOEs in the more competitive manufacturing sector had also scaled back non-salary benefits, such as the provision of company housing, schooling, etc. Large generation firms also started to focus more narrowly on their core business, making possible huge labor-savings. Given the generators' limited ability to pass cost increases on to customers, e.g. due to rising coal prices, efficient operation became a necessary condition for survival.

Fourth, demand was growing at breakneck speed and all market participants needed to invest in new generation capacity to defend or improve their market shares. This required vast amounts of capital and firms could not afford to waste money on inefficient operations. Without the divestiture, it would have been difficult for the SPC to participate wholeheartedly in the construction of new capacity without establishing dominant positions in some regions. Given the more level playing field, all firms were eager to compete aggressively for the right to satisfy the new sources of demand.

Fifth and perhaps most importantly, the reforms put forward a clear end-game for the industry. The plans to deregulate prices and establish competitive wholesale bidding did move forward and trials were organized in two regions in 2004 and 2005. Supply shortages, lack of interregional transmission capacity, and allegations of unfair behavior by the transmission companies in charge of dispatch made the government decide to postpone price deregulation in 2006. Nevertheless, market participants anticipated that price competition would be put in place eventually. The wholesale price for new plants was already fixed at a constant level by region and fuel type, and regulated prices for older generation units were expected to converge to these re-

sequently, SERC launched the "Coal and Electricity Prices Co-move" policy to arbitrate disputes over coal and electricity pricing, but it seems that both sides and even the end users of electricity are unsatisfied with this regime (Wang, 2007). The evolution of prices for electricity, fuel, and the general consumer price index is illustrated in Figure A.1 in the Appendix.

gional averages. Gradually, firms were becoming residual claimants on their efficiency improvements.

As a developing country, the first priority for the central planners was to assure supply and connect all end users to the grid. With this task more or less completed by the late 1990s, attention moved to operational efficiency. The plans drawn up during the capacity glut following the Asian financial crisis (1999-2000) were put on hold as the economy recovered from recession in 2002 and the economy soared in 2004 following China's entry in the WTO. The electricity shortages caused by the unexpectedly strong demand increase and the reluctance of some producers to generate power at a loss as coal prices improved more rapidly than electricity prices shifted focus back to supply assurance. However, by the time of the 2008-09 cyclical downturn, the focus was again on efficiency and conservation. The lack of real price competition in the wholesale market is very much perceived as a temporary postponement of the general reform process and firms are competing to be in a strong position when the next phase starts.

With respect to future reforms, SERC has confirmed its plan to work towards genuine price competition (Zhang 2008), but the State Council (2007) indicated it would not happen in the immediate future.[11] The dispersed market structure and surveillance of anti-competitive behavior have to be more firmly established and dispatch rules need to be more reliable before price liberalization would be contemplated. Even the OECD (2010) has counseled a cautionary approach and recommended in particular to first strengthen the rule of law. After a cyclical decline in electricity demand, a large further increase is expected between 2010 and 2020. Given China's current status as the world's leading emitter of CO2, renewable energy sources and a focus on conservation have become more prominent at this stage, which fits well with a continued focus on operational efficiency.

3 Empirical model

3.1 Estimating equations

The derivation of the key estimating equations follows Fabrizio et al. (2007) with a few modifications. Given that Chinese electricity generating firms do not have direct control over prices and demand is highly inelastic, a cost minimization framework is most appropriate to model short-run firm behavior. The Leontief functional form for

[11] Given SERC's lack of autonomy, the National Development and Reform Commission, an important department of the State Council, remains the primary institution in charge of counteracting anti-competitive behavior and setting end-user pricing.

the production function reflects the inability to substitute in the short run between fuel, on one hand, and capital and labor input, on the other hand.[12]

$$\begin{aligned} Q &= \min_{M,L} \Big\{ f_1(M, \beta, \varepsilon_M), f_2(K, L, \alpha, \varepsilon_L) \Big\} \\ &\text{s.t.} \quad Q \geq \bar{Q} \end{aligned} \tag{1}$$

It is a very intuitive specification at the plant level, but should also be appropriate for the particular sample of firms we work with. While several of them belong to a single ultimate owner, most firms only own a single large generation unit.[13] We know that in 2002 almost three quarters of the total thermal generation capacity, and even more of the actual generation, was accounted for by just 855 units of at least 100 MW each (OECD, 2010). Our sample contains 1,023 active firms in that year, implying an average of only 0.84 large generation units per firm. Given that matching demand and supply is somewhat localized, substitution between plants within a firm has to be extremely limited. By 2006, the average number of large units per firm had only increased to 1.08, and these now accounted for an even larger share of total generation.

Two factors limit the scope for substitution even further. Only 4% of electricity generated by fossil fuel came from oil or gas-fired plants. Relative price changes for competing fuels, an important reason for substituting between plants in other countries, hardly plays a role in China. As fuel-intensity is relatively constant within a technology, any substitution between plants would have a limited impact on relative input use. Moreover, the remnants of the dual-track pricing system insulates some plants entirely from market forces, especially early on in the sample. Young (2000) describes how market prices give appropriate incentives at the margin for efficient resource allocation in spite of a large volume of transactions being conducted at regulated 'plan' prices. However, the 'plan' prices in this industry were fixed at the plant not the firm level, while existing producers had hardly any scope to 'grow out of the plan.' This again blunts the incentives for intra-firm substitution.

In equilibrium both terms in the production function will hold with equality. A first-order Taylor approximation to any monotonically increasing $f_1(\cdot)$ function immediately produces a log-linear material demand equation:

$$\ln M_{it} = \beta_Q \ln Q_{it} + \beta_i + \beta_t + \varepsilon_{it}^M \tag{2}$$

[12]This specification was first used in Van Biesebroeck (2003) to capture a similar inability to substitute between components and other production factors in automobile assembly plants.

[13]This is especially likely to be true for the 15% of firms that were owned by regional governments at the start of the sample period and the 19% of firms that were foreign owned.

M comprising both fuel and non-fuel expenditures,[14] and the error term ε^M captures measurement error and factors that affect a firm's material efficiency. We include time and firm-fixed effects to soak up some of the productivity heterogeneity. Because we only observe output and material input in value terms, we face a missing data problem for input and output prices which is discussed and addressed below.

Capital and labor input are assumed to be substitutable to some extent. Assuming that the $f_2(\cdot)$ function takes the Cobb-Douglas functional form, as Fabrizio et al. (2007) do, implies a coefficient of one on output in the labor demand equation which is rejected by the data. Instead, we assume a more general CES production function:

$$Q \quad = \quad \gamma \left(\alpha K^{\rho} + (1-\alpha) L^{\rho}\right)^{\frac{\nu}{\rho}} \; e^{\varepsilon_L}.$$

α captures the relative importance of capital, ν measures the returns to scale, and $1/(1-\rho)$ is the elasticity of substitution ($\rho < 1$).

We treat capital input K as quasi-fixed in the short run as this is predetermined before labor and material input are decided. In the Chinese case, this applies even more strongly as the investment strategy of firms in the electricity sector is subject to government approval. The main job of the plant manager is to choose labor input each period to minimize the total wage bill, while satisfying the output constraint and taking into account the capital stock which can vary over time. The first order condition for labor amounts to

$$W \quad = \quad (1-\alpha)\nu\lambda Q^{\frac{\nu-\rho}{\nu}} L^{\rho-1}.$$

W is the wage level and λ is the Lagrange multiplier associated with the output constraint, i.e. the shadow price of output.

In logarithms, the additive term $\ln \lambda_{it}$ appears in the demand equation and it is expected to vary with the available capital, the market environment, and firm-specific conditions, such the ownership of other generation plants by the same firm. As proxies, we include the capital stock, time and firm-fixed effects. Fabrizio et al. (2007) use 'plant-epoch' fixed effect for periods in between large investments, but we explicitly include the capital stock. Generation capacity is adjusted more frequently at the firm level (our unit of analysis) and the rapid growth in electricity demand leads to frequent capacity additions even at existing facilities. The estimating equation for

[14] Our data only contains information on total intermediate material inputs, which combines 'fuel material input' and 'industrial intermediate inputs'. The latter consists of transportation cost, repairs and storage cost, and intermediate service inputs, such as interest expenditure, advertising, insurance, education and travel cost. The assumption that total material input is proportional to output is often made to justify estimating a production function in value added terms—see Van Biesebroeck (2007) for a discussion.

labor demand is

$$\ln L_{it} = \alpha_Q \ln Q_{it} + \alpha_W \ln W_{it} + \alpha_K \ln K_{it} + \alpha_i + \alpha_t + \varepsilon_{it}^L, \quad (3)$$

with $\alpha_Q = (\nu - \rho)/(\nu(1-\rho)) > 0$ for realistic values of the parameters and $\alpha_W = -1/(1-\rho) < 0$. ε_{it}^L captures measurement error, productivity shocks, and remaining variation over time in the shadow price of output.

To estimate the two factor demands (2) and (3), we need to address the missing price bias, the identification and nonrandom selection of restructured firms, and the simultaneity of productivity shocks with input choices.

3.2 Missing price bias

To estimate equations (2) and (3), we ideally would like to use physical quantities for inputs and output. As these are unavailable for material input (coal) and electricity output, we have to use material input expenditure and electricity revenue instead. Firm-specific deviations from the average price level are then omitted variables that enter the error term. They can cause inconsistent estimates if they influence the output level or are correlated with the restructuring effect.

On the output side, the constraints on electricity pricing discussed earlier limit the scope for different price evolutions across firms. State-owned companies sell most of their electricity at pre-determined transfer prices to the distribution networks. The IPPs sell at differentiated tariffs, but these are determined by a constant formula that includes the firms' ownership type, the date and size of initial investment, and market trends that are common to all firms. To the extent that the cross-sectional heterogeneity is constant, it will be captured by the included firm-fixed effects.

On the input side, the dual-track price system provides some firms with access to power coal at a low regulated price for some of their input needs. Other firms, especially younger IPPs, have to pay higher market prices. As the differential between the 'plan' and the market price fluctuated over time, see for example Wang (2007), the value of preferential access also fluctuated which is likely to induce some output variation.[15] Note, at the same time, that the gradual phaseout of subsidized coal gives restructuring firms greater incentives to operate their plants more efficiently, providing yet another channel for the reforms to be efficiency enhancing.

The importance for our application is that average prices faced by the group of restructured and control firms potentially evolved differently. For example, a more rapid increase in the average coal price paid by restructured firms, compared to firms

[15] There have been instances of firms deliberately choosing to halt production to avoid losses when coal prices soared on the private market and regulated electricity prices did not adjust.

in the control group, would induce an upward trend in their measured material input expenditures even without any change in output or productivity. This would bias the estimated productivity benefits of the reforms downward. In contrast, if the average electricity price increased more rapidly for restructured firms, we would overestimate the restructuring benefits.

The evolution of the relative prices faced by the two groups of firms is difficult to determine as there are two opposing trends. The growing importance of market prices increases the relative price ratio, i.e. it raises the average price paid or received by restructured firms relative to prices of control firms. In contrast, the growing gap between subsidized and regulated prices, because subsidized prices tend to increase more slowly than market prices, reduces the relative price ratio.[16] The fact that differences in coal and electricity prices have opposite effects makes it even harder to sign the expected bias.

To address this measurement problem, Du et al. (2008) replaced the dependent variable in the material demand equation (plant-level fuel input) with provincial fuel use and the explanatory variable in both equations (plant-level electricity output) with the provincial electricity demand. Using the aggregate variable as an instrument instead of a proxy would be a more standard approach, but that would be impossible for the material input. The weak correlation between firm-level and provincial variables in our sample makes this approach problematic anyway.[17]

An alternative solution would be to include deflated aggregate sales as an additional control in the input demand equations. Klette and Griliches (1996) have shown that this absorbs all output price heterogeneity if the industry can be characterized as monopolistically competitive with constant elasticity of substitution demand. In the Chinese electricity industry, it is implausible that firm-level price changes are always proportional to province-wide demand changes. They are the result of market power by regional monopolies and of variations over time (as market prices fluctuate) in the value of political connections that give some firms preferential access to subsidized coal or higher electricity tariffs.

[16] These effects can be seen from the following change in the relative price ratio:

$$\frac{s^1 + (1 - s^1)(P_S^1/P_M^1)}{s^0 + (1 - s^0)(P_S^0/P_M^0)} - 1.$$

The 0 and 1 superscripts denote time. s is the share of the input or output of restructured firms subject to market prices (assumed one for the control group). P_S/P_M indicates the relative subsidized-to-market price ratio. Because this ratio is less than one in both periods, an increase in s raises the average price more for restructured firms. However, as $P_S^1/P_S^0 < P_M^1/P_M^0$ the subsidized-to-market price ratio falls over time and the average price rises more slowly for restructured firms.

[17] As the coal market was only liberalized at the very end of the time period that Du et al. (2008) study, heterogeneous price changes were less of a problem for them.

In a case study of the Chinese power coal market, Mathys (2011) investigates which variables—firm characteristics and market features—have the most explanatory power for plant-level electricity prices and access to regulated power coal. Firm-location is found to be the most important factor as it determines ease of access to domestic mines, to imported coal, and to the congested transportation infrastructure. Location also controls for deviations from average electricity prices: relative price differences within provinces tend to be stable, but there is some variation in provincial price regulation over time. Firm age, size, and ownership are found to matter as well, as they help predict historical plan allocations and bargaining power.[18]

In the estimating equations, we replace the implicitly included difference between firm-specific and average prices with a set of interaction terms. Province dummies and age are collinear with the firm and time-fixed effects, but their interactions are valid controls. Firm-size and the share of state-ownership do vary over time and can be included directly, in addition we interact them with the provincial dummies and firm-age. The ownership variable is correlated with the restructuring dummy and including it slightly reduces the estimated treatment effect (in absolute value). We will report results including and omitting this variable in the set of price controls.

3.3 Identifying treated firms

The 2002 reforms affected all firms indirectly as the industry restructured and competition intensified. Firms that were divested from the State Power Company, the integrated public utility, were impacted much more directly because their ownership and often their management changed, in addition to the regulatory framework governing their actions. We classify firms that were officially denoted as state-owned in 2002 as 'treated'. They are identified from the variable 'legal structure of Chinese company ownership' as either state-owned companies (type 110) or state-solely-funded corporations (type 151). For this group of firms the $STATE_0$ dummy is set to unity in the entire period and to zero for firms in the control group, which are of private, foreign, collective, or mixed ownership.

Du et al. (2008) adopt an alternative definition of restructured firms as those companies originally controlled by the SPC or the Ministry of Electricity Power. It excludes some firms owned by the central government through other departments, while including some SPC subsidiaries that already had mixed ownership in 2002. It is less certain they all these firms were directly impacted by the 2002 restructuring.[19]

[18] The legacy of the planned period allows state-owned firms to access 'plan' power coal prices guided by National Development and Reform Commission and, equally important, guaranteed transportation by the Ministry of Railways.

[19] Some subsidiaries had already transformed to shareholding companies and were listed on the

Legal entities that are either subsidiaries of SPC prior to 2002 or that are subsidiaries of the Big Five generators created from the SPC breakup can be identified in the data set based on their name.[20]

Using the first definition, 36% of firms active in 2002 are considered treated and they accounted for 40% of industry revenue. The second definition ends up with a more narrow definition and the corresponding shares are 22% of firms and 50% of revenue. A third, broader definition of treatment is to include all firms with majority state-ownership of their capital in 2002, which is observed independently from the firms' formal ownership type classification. In this case 44% of firms active in 2002 are considered treated and they account for the same share of aggregate revenue. We will present estimates using all three definitions.

The objective of the analysis is to assess whether the reforms boosted productivity in restructured fossil fuel-fired electricity generation firms. As we need to include firm fixed-effects to help control for endogeneity problems and missing price bias, we cannot identify differences in the level of input demand between restructured firms and a control group of IPPs. We only measure whether their input demands evolve differently over time by interacting the constant $STATE_0$ dummy with a set of time dummies or a single post-reform dummy.

Introducing both the price and restructuring controls in the factor demands leads to the following two estimating equations:

$$\begin{aligned} \ln(EMPLOYMENT_{it}) &= \alpha_i + \alpha_R \ln(REVENUE_{it}) + \alpha_W \ln(WAGE_{it}) \\ &\quad + \alpha'_P X_{it} + \sum_{\tau=2}^{T} \Big(\alpha_\tau + \lambda_\tau STATE_{0i}\Big) \cdot I_{[YEAR_{it}=\tau]} + \varepsilon^L_{it} \end{aligned} \tag{4}$$

$$\begin{aligned} \ln(MATERIAL_{it}) &= \beta_i + \beta_R \ln(REVENUE_{it}) \\ &\quad + \beta'_P X_{it} + \sum_{\tau=2}^{T} \Big(\beta_\tau + \mu_\tau STATE_{0i}\Big) \cdot I_{[YEAR_{it}=\tau]} + \varepsilon^M_{it} \end{aligned} \tag{5}$$

The set of α_i and β_i coefficients are firm-fixed effects. Electricity output is replaced by $REVENUE$. X represents the set of variable-interactions to control for firm-level price differences, as discussed earlier. The coefficients are allowed to differ in the two equations as $\alpha'_P X$ only controls for firm-specific electricity prices, while $\beta'_P X$ additionally controls for coal price differences. The capital control in the labor equation is included in X.

The coefficients of interest, λ_τ and μ_τ, are normalized to zero in the first year of the sample. The uninteracted time dummies, α_τ and β_τ, control for changes in aggregate

stock exchange. Their management is more likely to have been stable following the reforms.

[20]Some firms with unrelated names are still defined as treated if a majority of their capital is controlled by one of the Big Five firms.

demand, but also for indirect, industry-wide effects of the reform, e.g. changes in average electricity prices.

3.4 Estimation

The key simultaneity issue is that productivity shocks affecting factor demands are likely to be correlated with output.[21] If output is determined exogenously or fixed before productivity shocks are realized, e.g. by a central or provincial government bureaucracy, there would not be a problem. However, it seems reasonable to assume that managers can adjust the amount of electricity production to some extent after observing idiosyncratic shocks to labor and material productivity. This endogeneity problem is likely to be more severe in the material input equation, as fuel-use is closely tied to output. Adjusting a level of employment that was based on demand expectations is not always easy, especially in a highly regulated sector with a lot of state ownership.

Fabrizio et al. (2007) used aggregate electricity demand at the state level as an instrument for plant-level output. For this approach to be effective, firm-level electricity revenue and province-level electricity consumption need to be positively correlated. In our sample, the association is quite weak: the correlation is only 0.067 pooling all firm-year observations. There are several reasons for this, some of them unique to the Chinese situation.

First, the correlation is diminished because of heterogeneity in electricity prices which is largely outside the firms' control. Second, many provinces are large and contain regions where firms are de facto local monopolies, only partially affected by province-wide demand fluctuations. Transmission capacity is often a binding constraint on the system (OECD, 2010). Third, provincial demand and production are often unbalanced. For example, under the 'West Development Strategy' the government launched a vast project to transport electricity from western provinces to the developed coastal area. Weak instruments will lead to large standard errors and in finite samples to inconsistent and biased estimates (Verbeek, 2008).

An important advantage of our analysis over Du et al. (2008) is the availability of a relatively long panel (ten years), allowing us to include firm-fixed effects. These already soak up the heterogeneity in the cross-firm dimension and reduce the simultaneity problem in the quasi-differenced equations. As instruments for firm-level revenue, we use information from outside the industry to proxy for the more localized electricity demand faced by the generators. Total manufacturing output and

[21] The exact timing assumptions for input and output decisions and the realization of shocks that Van Biesebroeck (2003) employs, would also work here.

employment in the same 6-digit region (dìqū) turn out to be more strongly correlated with firm-level electricity output.[22] In a robustness check we add annual provincial temperature and electricity consumption as additional instruments which are weaker, but still significant in a first-stage regression.

We implemented two alternative approaches to address the potential output endogeneity. One solution that is valid even in the presence of autocorrelated errors is to estimate the factor demands in first differences and use twice lagged revenue as instrument for the change in revenue (Blundell and Bond, 1998). It does reduce the sample size considerably as our panel is not at all balanced. Du et al. (2008) have used provincial thermal power output as a proxy for plant-level electricity output. The weak correlation of the firm and province-level variables in our sample period makes this an unattractive solution for us, but in the absence of serial correlation we can use lagged firm-level revenue as a proxy for the current revenue (still including firm-fixed effects). It allows consistent estimation of all coefficients except for the output elasticity, which is not of direct interest.

Equations (4) and (5) follow a traditional difference-in-differences setup. Negative values for λ_τ and μ_τ after 2002 would indicate larger efficiency gains for restructured than for control firms, always relative to each group's own initial situation. Bertrand, Duflo, and Mullainathan (2004) argue that serial correlation may underestimate the standard error of the treatment effects and hence overstate significance levels in conventional difference-in-differences. Their suggested solution is to use longer time-differences. We collapse the panel into a pre and post-reform period, which should help if the serial correlation does not span the entire period. In addition, we implement the randomized inference approach suggested by the same authors.

4 Data and summary statistics

The firm-level data we use are collected through annual surveys by China's National Bureau of Statistics. The sample covers the 1998 to 2007 period and includes all firms in the fossil fuel-fired electricity generation sector (Chinese Industrial Classification code 4411) that are either state-owned or have annual sales above 5 million RMB. Because the threshold is far below minimum efficient scale in the sector, the sample includes the universe of generation firms.[23]

[22] In China, 75% of electricity demand comes from industry.

[23] The sales threshold of 5m RMB equals approximately $US 600,000 during the sample period. A back of the envelope calculation suggests that each installed megawatt of generation capacity yields 1.93 million RMB of annual revenue (24 hours x 365 days x 55% average capacity utilization rate x 400 RMB/MWh average wholesale price for electricity generated from fossil fuel). Each firm with

As mentioned before, electricity revenues (*REVENUE*) and intermediate input expenditures (*MATERIAL*) are observed in value terms, not in physical quantities. The latter contains the expenditures on both fuel and non-fuel material inputs. The *WAGE* variable is defined as the total labor compensation, including wage and non-wage expenditures, divided by total employment (*EMPLOYMENT*).[24]

Four sets of variables are included in the polynomials to control for electricity and coal prices. Firm size is measured by total fixed assets, firm age is calculated from the reported year of creation, the percentage of capital that is state-owned captures the ownership structure, and provincial dummies capture location and transportation conditions. The uninteracted provincial effects are absorbed by the firm-fixed effects, but the interactions with the other three variables do vary over time.

Table 1 contains summary statistics for all firm characteristics, listing the state-owned 'treated' firms separately from the control group. We report these statistics for 2002 at the eve of the reforms. 23% of firms active before 2002 exit the sample before the reforms are launched. These tend to be relatively small and only account for 15% of revenue over that period. At the same time 31% of firms active in 2002 were not yet in the sample in 1998. To follow firms over time, we rely primarily on the officially assigned firm-identifiers. For exiting firms, we verify whether they re-enter in subsequent years with a different id using information on birth date, zip code, and name. 10% of the firms in our sample have undergone some restructuring that lead to a new id.

The statistics indicate that average revenue is 17 percent higher for state-owned firms, but the difference is not significantly different from zero. They do employ a lot more workers, have a much higher wage bill, and use more fixed assets, but only the first two differences are statistically significant. Both groups of firms spent approximately 73 percent of revenue on fuel and other material inputs. As expected, state-owned firms tend to be a lot older and the average share of their capital that is owned by the state is four times as high. Without controlling for anything, the employment/revenue and material-revenue ratios are significantly higher for 'treated' firms.[25]

more than 3 MW of installed generation capacity should be included in the sample.

[24]For the summary statistics, revenues are deflated to 1998 with the ex-factory price index for the electricity industry, inputs with the fuel and energy purchase power index, and the labor remuneration with the consumer price index. The deflators do not influence the estimates as the model contains a full set of time dummies.

[25]Similar calculations for firms active in 1998 confirm the higher employment/revenue ratio for 'treated' firms. The difference for the material/revenue ratio is in the same direction but not statistically significant.

⇒ Insert Table 1 here ⇐

5 Results

5.1 Benchmark estimates

The impact of the 2002 reforms on input use is estimated using equations (4) and (5). Panel (a) in Figure 1 plots the coefficients and 95% confidence intervals for the year dummies in the labor demand equation. The blue markers (solid line) are for the firms that were state-owned in 2002 and the red markers (dashed line) are for the control group of IPPs. Labor efficiency is fairly constant for both groups in the initial years and until 2004 there is no discernable difference. In later years, the improvement for restructured firms accelerates and a gap opens up which is statistically significant at the 10%, but not at the 5% level. It reduces the employment difference between the two groups that was apparent from the summary statistics. By the end of the sample period in 2007, the 0.088 log-points difference implies that labor input in restructured firms has decreased by 8.0 percent more than the 5.1 percent decline for other firms.[26]

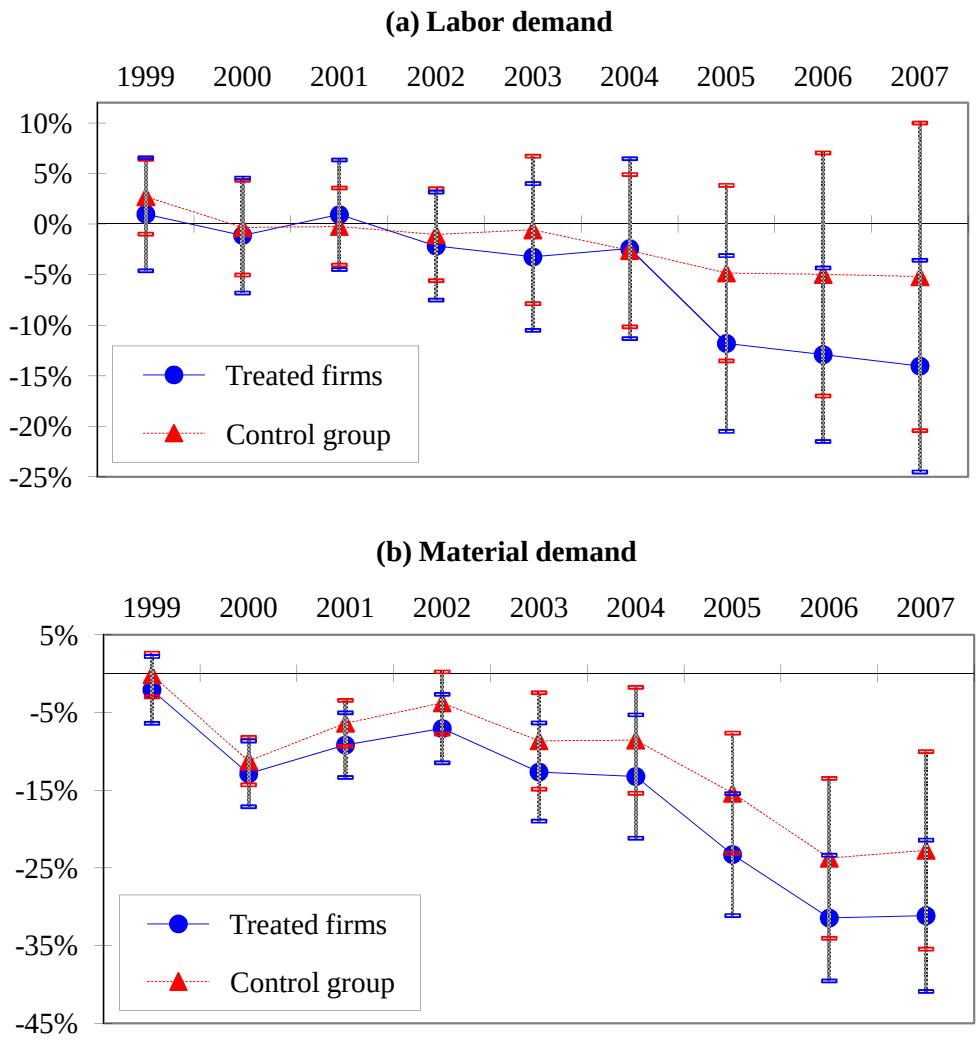
The figure in panel (b) illustrates a similar evolution for material input expenditures. While the average control firm lowers its material input by 20.3 percent between 1998 and 2007, the average restructured firm lowers it by 26.8 percent, a 6.5 percent additional decline. At -0.084, the log-points difference in 2007 is very similar to the estimate in the labor demand equation. Because the gap between restructured and other firms now appears a few years earlier and the coefficients are estimated more precisely, the divergence shows up even more clearly.

The estimates in Figure 1 include firm-fixed effects, control for unobserved price differences, and instrument for output using local manufacturing activity. The full set of estimates is reported in Table A.1 in the Appendix; the last nine coefficients directly measure the differences for the two groups of firms. In the same table, we also report results without instrumenting which would be appropriate if output was predetermined. Given that all state-owned firms have output quotas to fill, that the majority of sales is covered by long-term contracts and that no firm has direct price-setting power this is not entirely implausible. The differences are of similar magnitudes, -0.075 for labor demand and -0.094 for material input in 2007. The standard errors are a lot lower and the differences for 2005, 2006, and 2007 are all significant at the 5% level for labor and at the 1% level for materials.

As argued by Bertrand et al. (2004), serial correlation in the error term can lead

[26] A difference of -0.088 in log-points translates into an $\exp(-0.088) - 1 = 8.4$ percent difference. At the reduced input level of the control group, it implies an additional 8.0 percentage points decline.

Figure 1: Evolution of factor demands for firms in the treatment and control groups



to an overestimate on the coefficients in conventional difference-in-differences. Both equations, but especially labor demand, do not pass the Wooldridge (2002, p. 282–283) test for serial correlation in linear panel models.[27] One solution is to collapse the data into two periods with a $POST_t$ dummy indicating the post-reform period.

Moreover, Bergh (1997) suggests that it can take several years for performance effects of a divesture to fully materialize. Most changes in ownership type in our data set occur between 2002 and 2004. It also took time for the contemporaneous liberalization of the coal market to lead to higher input prices and profitability problems. As a result, many firms might not have responded to the new industry structure right

[27]The material equation passes the Breusch–Godfrey test for serial correlation which assumes homoskedastic errors, but even this test still suggests a (mild) problem for the employment equation (the p-value of rejecting the null hypothesis of no serial correlation is 0.152).

away. To allow for a delayed effect of the restructuring, we estimate the model with two alternative post-reform dummies: *POST2002* and *POST2004*.

⇒ Insert Table 2 here ⇐

Table 2 reports the estimates of the labor and material input equations using the same estimator as before. The full set of time-varying restructuring effects in (4) (and similarly in (5)) is replaced with a single term $\lambda_P \cdot STATE_{0i} \cdot POST_t$ that switches from zero to one in the post-reform period for treated firms. This parsimonious specification also makes it easier to compare the results under alternative estimation assumptions below. Note that we still include a full set of (uninteracted) time effects α_τ to control for changes that affect all firms, such as changes in technology, the business cycle, and the market environment.

The coefficients on firm-level revenue and wages are estimated consistent with expectations. The revenue coefficient in the material input equation, which includes both fuel and nonfuel expenditures, is a direct estimate of the output elasticity of materials. It is estimated close to unity, as expected, and in between the coefficients for the separate fuel and nonfuel expenditure equations in Du et al. (2008).

Taking our production function at face value, the revenue coefficient in the labor equation equals $(\nu - \rho)/(\nu - \nu\rho)$. It should be positive but less than one if returns to scale are increasing, the usual assumption for electricity generation. This is indeed what we find, although the coefficient is not significantly different from zero when we instrument for revenue.[28] The strong correlation of firm-level revenue over time is indicative of limited changes in generation capacity between consecutive years and stable long-term contracts to deliver electricity. Firms only have limited ability or incentive to respond to short-term productivity fluctuations. This makes it difficult to identify the revenue coefficient, but also limits the potential endogeneity problem.

Fabrizio et al. (2007) and Du et al. (2008) both did not obtain significant coefficients on output in their labor demand equations either. In contrast with those two studies, we do find a negative and significant coefficient on the wage rate. The absolute value of the wage coefficient equals the elasticity of substitution $1/(1 - \rho)$. The 0.26 estimate suggest substitution between labor and capital is quite low, which is intuitive for electricity generation.

[28] The results in Table A.1 in the Appendix show a very precisely estimated, but potentially upwardly biased estimate on revenue in the labor equation without instrumenting. Returns to scale are increasing if the revenue coefficient is larger in absolute value than the wage coefficient. The two point estimates in Table 2 are not significantly different and weak instruments for revenue might bias that coefficient downward.

The last coefficient in each column—the interaction between the restructuring and the post-reform dummies—measures the gap in input demand for treated and control firms in the post-reform period. The negative coefficients indicate a relative efficiency gain for former state-owned firms. Using the two alternative reform periods, they are estimated to experience an additional reduction of 4.1 or 7.0 percent in labor use and a reduction of 3.9 or 5.0 percent in expenditures on material (including fuel). The higher effects for both input factors in the limited 2004–2007 period are significant at the 5% and 1% level.

5.2 Verifying robustness

In Table 3 we report the results of several robustness checks to verify the sensitivity of the estimated restructuring effects to various assumptions. The benchmark results using the *POST2004* dummy are repeated in the top row.

Not controlling for the omitted price bias leads to a slightly stronger effect on employment, but a weaker effect on material expenditure. These opposing changes are intuitive because only the electricity price is omitted from the first equation, while the second equation misses both the electricity and coal prices which have opposite effects and the coal price is likely to vary more. In light of our earlier discussion of the likely bias, the direction of the changes suggests that prices increased more rapidly for treated than for control firms. This would be consistent with the share of their input needs coming from subsidized coal and the share of their output sold at below market rates both declining over time. Excluding the share of state-ownership from the set of price controls, as it might be correlated with the restructuring dummy, has only a very small effect on the point estimates.

⇒ Insert Table 3 here ⇐

The next set of results in Table 3 rely on alternative approaches to control for the endogeneity of revenue in the two input demand equations. Adding two additional instruments that vary only at the province-year level, average temperature and total electricity demand, raises the estimated restructuring effect for materials, but it also increases both standard errors. Following an identification approach from the dynamic panel literature and using twice lagged revenue as an instrument for the equation in first differences raises the estimated effect for employment. Using lagged revenue as a proxy for current revenue lowers the point estimates for both effects slightly, but raises the estimation precision for the effect on employment greatly. Given that our data set is far from balanced, we lose a nonnegligible share of observations with the last two estimators. While the point estimates depend somewhat on

the exact identification assumption, the signs and general magnitudes of the effects are preserved.

To further alleviate concerns about serial correlation of the residuals, we implement the randomization inference method suggested by Bertrand et al. (2004). This is a group jacknife approach, where we first run the FE-IV regression on half of the firms in the sample. In the following regressions we randomly replace ten of the firms with ten randomly drawn firms from the half of the sample that was not used initially. We can repeat this procedure 109 times and obtain as many different estimates for the restructuring effect. A similar analysis is performed replacing twenty or fifty firms at a time, which allows 55 and 22 regressions respectively.

In Table 3 we report the average and standard deviation for the coefficient of interest across all estimates. The modest changes suggest that autocorrelation is not a serous issue once we limit the comparison to the periods preceding and following the reforms. The large sample approximation to the standard errors also seems surprisingly accurate. The average point estimate on the restructuring effect is at most reduced by one eight and it always remains significant at the 10% level.

The difference-in-differences approach controls for unobservable differences across firms that are constant over time. The summary statistics illustrated that the treated state-owned firms differ from other firms in a number of observable ways and one might be concerned that the probability of restructuring is related to observable characteristics as well. By including these characteristics in the regressions we already controlled for differences in performance potential, but we could additionally control for nonrandom selection into treatment. The treatment evaluation literature has developed several approaches, see Imbens and Wooldridge (2009) for an overview, and we implement one straightforward matching estimator.

To make sure that treated firms are benchmarked to comparable control firms, we adjust for the imbalance in their covariates as follows. We first match each treated firm to its nearest neighbor in covariate space using the Mahalanobis distance metric. We then estimate the input demand equations on the restricted sample of matched firms. This has the advantage that the regression does not need to fit firms in the control group with covariates that are very different from those observed for treated firms. On the restricted sample of matched firms, the second stage regression produces very similar estimates on the $STATE_{0i} \cdot POST2004_t$ interaction terms.

The results turn out to be more sensitive to one final robustness check: the definition of restructured firms. In Table 4 we report estimated restructuring effects using three alternatives definitions. While the benchmark definition suggests positive and significant productivity effects of restructuring, the evidence is weaker using the al-

ternative definitions. For expenditure on materials the coefficients are still estimated negatively using both alternatives, but for Big 5 subsidiaries the effect is only significant at the 10% level and for firms with majority state-ownership of capital the effect is not significant. For labor demand the effect is reduced to one third for firms where the state is majority shareholder, while employment is even estimated to increase (in relative terms) in Big 5 subsidiaries.

⇒ Insert Table 4 here ⇐

It turns out that the exact firms identified as treated using the three alternative definitions are rather different. Only half of the Big 5 subsidiaries were classified as state-owned in 2002 and only slightly more had the state as majority investor. Several of them had already transformed to shareholder companies before 2002 and some were even listed on the stock exchange. Most of the restructuring of these units might already have taken place before 2002. At the time of their ownership changes they often underwent internal restructuring, introduced corporate governance changes, and sometimes started foreign partnership.

Big 5 subsidiaries tend to be the larger firms in the industry. While they make up less than one quarter of all firms, they represent more than half of the firms in the top quarter by revenue. Moreover, their employment to revenue ratio is less than two thirds of the sample average, while the same ratio is one half above the average using the other two definitions. It is not entirely surprising that these firms did not reduce their workforce aggressively after 2002. Moreover, while revenue growth in restructured firms lags the sample average after 2002 using all three definitions, the difference is a lot smaller for Big 5 subsidiaries than for formerly state-owned firms.

A problem with the comparison for different definitions in panel (a) is that the treatment group also changes. In the second panel of Table 4 we report results for the same regressions, but include only firms that are not considered treated according to any of the three definitions in the control group. The estimate of labor productivity gains is still largest using the first definition, but the differences are not as large now. For Big 5 subsidiaries, material expenditure declined by 3.8% more than for control firms, the largest of the three point estimates for the materials equation. None of the three material productivity estimates are now significantly different from each other.

The evolution of input use in firms with majority state-ownership suggests improved productivity in the post-reform period, but the point estimates are smaller than in the benchmark case and never significant. Firms with majority state ownership, but not classified as state-owned are found to behave differently. The presence of other owners seems to have already changed these firms' operations prior to the

2002 reform. In spite of a high ownership share, the state appears to act differently in companies that are not formally classified as state-owned.[29]

5.3 Heterogeneity of restructuring effects

The sensitivity of the estimates for alternative definitions of restructuring leads us to investigate whether effects might be heterogeneous across other dimensions as well. Since the start of the Chinese economic reforms in 1978, the coastal provinces in the East have developed a lot more rapidly than the rest of the country. Previous work for the manufacturing sector suggests that productivity levels and growth rates tend to be higher for smaller, often privately owned, firms and for new entrants which have concentrated in the East (Brandt et al. 2012).

To investigate whether such performance differences also apply to the power sector, we estimate the input equations on sub-samples, splitting the original sample in two by location, firm size, or age. The West, Central, and East regions are defined following the official classification of provinces in China's Statistical Yearbook. The old-young and small-large divisions are relative to the median firm in terms of fixed assets and date of creation. The cut-off points are a capital stock of 137.5 million RMB and a start-up year of 1993. Because we assign firms in the first year that we observe them and they vary in the number of years they remain active, the total number of observations in the two groups differ slightly.

$\Rightarrow$ Insert Table 5 here $\Leftarrow$

We report the FE-IV estimates on each of the sub-sample in Table 5. We expected that firms located in the East, young firms, and given the importance of scale economies in electricity generation also large firms would be more efficient irrespective of ownership type. Therefore, the largest potential for efficiency gains from restructuring and the largest coefficients (in absolute value) on the $STATE_{0i} \cdot POST2004$ interaction term should be found for firms in the West/Central, firms that are old, and small. This is exactly what we find for labor efficiency. The gains are positive (point estimates are negative) in five of the six samples and the effect is estimated stronger for firms in the West or Central regions than in the East (a -0.045 difference), for firms that are old (a -0.131 difference), and small (-0.083 difference). The last two differences are even significantly different.

[29] The vast majority of firms classified as state-owned have the state as majority investor (308 out of 369, or 83.5%). The 139 companies with state-majority ownership but not registered as state-owned firms are driving the differences between the first and third regressions.

To eliminate excess employment, worker resistance and union activity has to be overcome. It is intuitive that this is easier in small firms. In old firms the higher probability of future exit, due to bankruptcy or technological obsolescence, might be sufficient to overcome resistance to change and some employees might willingly look for more secure employment. Older firms also have a much larger historical burden of forced excess employment giving them a lot of scope for improvement.

The larger effects for worst performing firms leads to some convergence in operational efficiency, which is an expected outcome from greater market pressure. We also report the coefficients on the revenue variables in Table 5. The remaining variation indicates that a lot of potential for convergence remains. Along each of the three dimensions, the firms with the largest productivity effect of reform also have the highest output elasticity of employment.

For material efficiency, however, the relative strengths of restructuring effects always show the reverse pattern—they are stronger for East, young, and large firms—but the difference is only statistically significant (at the 10% level) for the small-large firm comparison. It suggests that the actions needed to improve material efficiency are different from actions that improve labor efficiency.

Improving material (fuel) efficiency requires operating the plants more efficiently. In the East, the rapid growth of electricity demand from manufacturing is putting greater pressure on the power system to increase output. The greater importance of market prices for coal, as plants are farther from the important coal mining areas in the West, could also play a role. At the same time, the higher level of economic development in the East could boost the deployment of more advanced technologies as well as more experienced management. This holds similarly for larger firms, where some of the gains might also come from better deployment of the plant-mix.

6 Implications

In this section we discuss three questions that put the estimated restructuring effects in context. What do point estimates imply? Which additional effects are not captured by the estimates? How efficient are new plants?

The estimates have direct implications for the aggregate resource use of the power sector. Fossil fuel-fired, mainly coal-fired units remain extremely important in China. By the end of the sample period in 2007 they accounted for 77.4% of total installed electricity generation capacity of 718 GW and even 83.3% of total electricity generation of 3,264 TWh.[30] In 2002, the group of treated firms accounted for at least 39.5%

[30]These statistics are from China Electricity Council: http://www.cec.org.cn/tongjixinxibu.

of all thermal electricity generation (based on the revenue statistics in our data set). If the estimated additional reductions in employment (of -0.072) and in material use (of -0.051) for these firms had not been realized, 22,100 additional workers would be employed in the electricity generation sector in 2007, workers not available for other fast-growing segments of the economy. Coal consumption would be approximately 27.4 million tonnes higher.

The impact on pollution is also nonnegligible. Aggregate statistics for the industry suggest lower levels of pollution per kWh of electricity: a 33% decline in dust emissions per kWh from 2002 to 2006 and 26% lower SO2 emissions by 2007 (OECD 2010). The estimated reduction in coal consumption translates directly into lower CO2 emissions. The above estimate suggests a reduction of approximately 78 million tonnes of CO2 emissions each year, more than the total for North Korea, the 43rd largest emitter in the world, or 1.4 percent of total U.S. emissions.

Aggregate statistics on the coal-intensity for the sector show a decline between 2002 and 2006 of 4.2 percent, from 383 to 367 g/kWh. This is remarkably similar to our estimate of a 5.0 percent improvement in material productivity. The two estimates are not entirely comparable as two factors that influence the aggregate coal-intensity did not contribute to the identification of our estimate. Greater efficiency of new plants which use more advanced technology and tend to operate at higher scale improves the aggregate statistic. On the other hand, an increased share of coal-fired plants in total electricity generation increases aggregate coal use per kWh.

The introduction of more efficient units does not contribute to the identification of our restructuring effect as each firm is implicitly compared to its own past performance by including the firm-fixed effects. Another omitted effect is the noticeable decline in input use by the group of control firms (see Figure 1). This is especially large for material expenditures. To some extent it might simply capture changes in (relative) prices for electricity and coal, but part of the decline is likely to be an indirect effect of the 2002 restructuring and the more competitive market environment it generated. Stronger competition is likely to improve the quality of entering firms as better performance is required for survival. It also accelerates the replacement of older, less productive units with more modern and efficient units.

Given all these additional factors, our estimates should be considered a conservative estimate of the restructuring benefits. The continued increase in China's electricity consumption, by a further 38% between 2007 and 2011 for a cumulative increase of 164% since the start of the reform, magnifies the effect of the efficiency gain.

The estimated efficiency gains are identified from changes in continuing firms and imply more rapid improvements in labor and material productivity for firms that were

state-owned in 2002 than for IPPs. At the same time, thermal generation capacity increased rapidly. It more than doubled from 266 GW at the onset of the reforms to 556 GW at the end of the sample period in 2007.

Using the estimated input demand equations, we can compare remaining discrepancies in efficiency among active firms at the end of our sample period and even look at new entrants. The firm-level residuals provide estimates for adjusted labor and material input use, correcting for revenue, wage, and unobserved price differences. We also subtract time effects that affect all firms, but leave the firm-fixed and the restructuring effects in the residuals.

Table 6 contains simple input-output ratios as well as the adjusted input use statistics calculated from the estimated equations. In the first panel, we compare state-owned firms in 2002, the treated firms in our analysis, with the control group of IPPs. The simple input-output ratios indicate that treated firms use markedly more workers. In logarithms the difference in material use is not statistically significant, but in levels it is (results in Table 1 before). Adjusting for observable differences using the estimated factor demands, the comparison points to significantly higher input use for treated firms. The difference is a lot higher for employment than for material expenditures, 0.572 versus 0.035, but note that the average expenditure on materials is eight times higher than on wages.

$\Rightarrow$ Insert Table 6 here $\Leftarrow$

The comparison in the next panel for firms that entered after the start of reforms shows a markedly different situation. Not only did the share of state-owned firms declines to 14.5 percent of new entrants compared to 36.1 percent before, they even used fewer workers and less material per unit of revenue than other firms. After adjusting for observable differences, state-owned firms still employ an excess of workers, but the gap with IPPs has declined from 0.572 for state-owned firms active in 2002, to only 0.187 for newly entered state-owned firms. Their material productivity is even estimated higher, but the difference is not significant.

Finally, the results in panel (c) of Table 6 compare input efficiency for restructured firms, distinguishing between firms that remained state-owned and those that changed ownership status. We already know from the benchmark estimates that these firms improved more rapidly than others, but we now find further differences within this group. In 2005, three years after the reforms started, adjusted employment and material use are respectively 31.2 and 11.1 percent lower (point estimates of 0.375 and 0.118) for firms that privatized. These are converging even more rapidly to the

original group of IPPs. Both differences are estimated very precisely.[31]

7 Conclusions

We have investigated the impact of regulatory reforms and the vertical unbundling of the dominant integrated firm in 2002 on the performance of electricity generation companies in China. The difference-in-differences method used by Fabrizio et al. (2007) to estimate labor and material input efficiency in the United States underlies the analysis, but we modify it to account for specific features of the Chinese situation.

Using panel data, we can include firm-fixed effects to help control for output endogeneity and missing information on input and output prices. Regional variation in the the evolution of manufacturing activity provides instruments to break the potential correlation between productivity shocks and output levels. Institutional details on the operation of the electricity and the power coal markets is exploited to construct a flexible proxy for missing prices. Detailed information on firm type and ownership is exploited to identify which firms can be considered directly treated by the reforms. We investigate the robustness of the results with respect to these three issues.

The results strongly indicate a positive impact on both labor and material input efficiency. We find that it did take a few years for the effects to materialize, which explains the weaker evidence in Du et al. (2008) who only had data until 2004. The benchmark estimates suggest that the average firm that was state-owned in 2002 reduced employment by 7 percent more than the control firms and material input by an additional 5 percent. The magnitudes of these reform-related input reductions are plausible compared to estimated reductions in factor use experienced by all firms between 2002 and 2007, 5% for employment and 20% for materials.

Firms that are expected to be less productive on average—those located in the West or Central regions, older, and smaller firms—show stronger improvements in labor productivity, but weaker change in material productivity. One possible explanation is that competitive pressure is sufficient to reduce excessive employment, but technological and/or managerial innovations are needed to improve material (fuel) efficiency. Restructuring effects are less pronounced when they are identified from a broader group of firms with majority state-ownership of equity, rather than from the official state versus non-state categorization. Subsidiaries of the Big 5 generation

[31] We show the comparison in 2005 because at the end of the sample period in 2007 an additional 43 restructured firms had exited. The adjusted input difference in 2007 is similar for employment (0.311***), but lower for material (0.036).

firms that were created from the breakup of the State Power Company, which include many firms of mixed ownership type and even stock market listed firms, on average did not experience a comparable decline in employment.

Looking towards the future, SERC has indicated that it still plans on liberalizing wholesale prices which would provide additional profit-maximizing incentives. Improved deployment of existing capacity can generate efficiency gains that go beyond single plants or firms. The addition of non-coal generation capacity in recent years increases the potential benefits of the reforms further, as more thermal plants will become marginal producers and responsive to market forces.[32]

Early experiments with competitive wholesale markets in two regions in 2004 and 2005 revealed a number of preconditions for efficient dispatching to become feasible. Transmission firms had to divested their generation assets, generators had to become residual claimants on their profits, and market distortions due to subsidized coal had to be reduced. Progress has been made in each of these areas. The key remaining impediments for the next phase in the reform process are the need for stronger rule of law and the establishment of a strong and independent regulator. These are political constraints which will fall to the new leadership to be installed at the end of 2012.

[32]The famous Three Gorges Dam hydroelectric project alone represented almost 5% of total thermal capacity in 2007. Nuclear capacity is scheduled to rise from 12 GW in 2010 to 24 GW in 2020, with another 25 GW of extra capacity in preparation. Wind capacity has increased slowly to 6 GW, but is becoming more of a priority for the future.

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Table 1: Summary statistics by ownership category (in 2002)

	State-owned firms	Control firms	Differences in means
Revenue (mil. RMB)	353	303	50
	(1008)	(636)	(51)
Employment	1,149	531	617
	(3107)	(722)	(127)***
Material / Revenue	0.855	0.750	0.105
	(1.411)	(0.360)	(0.059)**
Employment / Revenue	13.851	6.380	7.481
	(34.49)	(9.14)	(1.44)***
Fixed Asset / Revenue	2.371	2.003	0.368
	(5.612)	(4.428)	(0.323)
Wage / Revenue	0.146	0.076	0.101
	(0.291)	(0.081)	(0.012)***
Age	22.6	10.8	11.8
	(16.6)	(9.9)	(0.8)***
State-owned capital (%)	0.828	0.214	0.613
	(0.364)	(0.362)	(0.024)***
Observations	369	654	

Note: Standard deviations in brackets. ***, **, * denote significance at 1%, 5%, or 10% level

Table 2: Input demand equations prior to and following restructuring

Dependent variable: *(N=10,792)*	ln(EMPLOYMENT)		ln(MATERIAL)	
ln(REVENUE)	0.181	0.189	0.893	0.892
	(0.220)	(0.216)	(0.133)***	(0.132)***
ln(WAGE)	-0.260	-0.262		
	(0.051)***	(0.050)***		
$STATE_0$*POST2002	-0.042		-0.040	
	(0.027)		(0.018)**	
$STATE_0$*POST2004		-0.072		-0.051
		(0.035)**		(0.020)***
Weak identification test:				
Cragg-Donald Wald F-stat.	258.54	258.54	258.57	258.57
Stock-Yogo critical values (20% maximal IV size)	8.75	8.75	8.75	8.75
Overidentification test:				
Hansen J Statistic	0.405	0.416	0.119	0.138
Chi-sq(1) p-value	0.525	0.519	0.730	0.710

Note: IV-FE regression that includes firm and year fixed effects and controls for price heterogeneity (interaction terms of fixed assets, fraction of state-owned capital, and provincial dummies). Revenue is instrumented with manufacturing output and employment in a firm's 6-digit region (diqu). Standard errors are clustered at firm level. ***, **, * denote significance at 1%, 5%, and 10% level.

Table 3: Verifying the robustness of the restructuring effect estimates

Dependent variable:	ln(EMPLOYMENT)	ln(MATERIAL)
	Coefficients on $STATE_0$*POST2004	
Benchmark estimates	-0.072	-0.051
	(0.035)**	(0.020)***
Alternatives for omitted price bias:		
- Not controlling for omitted prices	-0.079	-0.043
	(0.032)**	(0.017)**
- Excluding state-ownership from	-0.076	-0.050
price controls	(0.035)**	(0.020)**
Alternatives for revenue endogeneity		
- Additional instruments for revenue	-0.070	-0.078
(provincial temp. & elec. demand)	(0.042)*	(0.029)***
- Estimate in first differences with	-0.099	-0.045
twice lagged revenue as instrument	(0.029)***	(0.026)*
- Lagged revenue as proxy	-0.067	-0.039
	(0.018)***	(0.023)*
Randomized inference		
- 10(109)	-0.074	-0.044
	(0.039)*	(0.023)*
- 20(55)	-0.077	-0.045
	(0.042)*	(0.022)**
- 50(22)	-0.076	-0.045
	(0.041)*	(0.024)*
Mahalanobis matching	-0.076	-0.041
	(0.034)**	(0.021)**

Note: Each statisic is estimated by a separate IV-FE regression with the same controls as in Table 2 and changes in the estimation strategy as indicated. ***, **, * denote significance at 1%, 5%, and 10% level. Standard errors are clustered at firm level.

Table 4: Alternative definitions of restructured firms

Dependent variable:	ln(EMPLOYMENT)	ln(MATERIAL)	Treated	Controls
	Coefficients on $STATE_0$*POST2004		(in 2002)	
(a) Using the full sample of firms				
Benchmark estimates (State-owned in 2002)	-0.072 (0.035)**	-0.051 (0.020)***	369 (36.1%)	654
Big 5 subsidiary	0.077 (0.029)***	-0.032 (0.018)*	228 (22.3%)	795
Majority state-ownership of capital in 2002	-0.038 (0.033)	-0.011 (0.020)	447 (43.7%)	576
(b) Using the same set of control firms in each case:				
Benchmark estimates (State-owned in 2002)	-0.068 (0.050)	-0.028 (0.031)	369 (45.8%)	436
Big 5 subsidiary	0.056 (0.032)*	-0.039 (0.019)**	228 (34.3%)	436
Majority state-ownership of capital in 2002	-0.060 (0.045)	-0.011 (0.025)	447 (50.6%)	436

Note: Each statisic is estimated by a separate IV-FE regression with the same controls as in Table 2, but defining the $STATE_0$ restructuring dummy in three different ways. Results in panel (a) use the full sample, results in panel (b) only include firms in the control group that are not considered treated using any of the three defintions. ***, **, * denote significance at 1%, 5%, and 10% level. Standard errors are clustered at firm level.

Table 5: Heterogeneous restructuring effects

Dependent Variable:	ln(EMPLOYMENT)		ln(MATERIAL)	
(a) By location	West/Central	East	West/Central	East
ln(REVENUE)	-0.318	0.312	0.797	1.024
	(0.745)	(0.219)	(0.325)**	(0.158)***
ln(WAGE)	-0.135	-0.309		
	(0.143)	(0.054)***		
$STATE_0$*POST2004	-0.112	-0.067	-0.027	-0.058
	(0.084)	(0.056)	(0.034)	(0.037)
No. of observations	4,776	5,664	4,776	5,664
(b) By age	Old firms	Young firms	Old firms	Young firms
ln(REVENUE)	-0.206	0.379	1.592	0.714
	(0.896)	(0.308)	(0.804)**	(0.225)***
ln(WAGE)	-0.166	-0.335		
	(0.135)	(0.069)***		
$STATE_0$*POST2004	-0.090	0.041	-0.029	-0.045
	(0.050)*	(0.048)	(0.042)	(0.027)
No. of observations	5,235	5,205	5,235	5,205
(c) By size	Small firms	Large firms	Small firms	Large firms
ln(REVENUE)	-0.030	0.456	0.745	0.849
	(0.294)	(0.277)*	(0.244)***	(0.143)***
ln(WAGE)	-0.181	-0.343		
	(0.076)**	(0.055)***		
$STATE_0$*POST2004	-0.102	-0.019	-0.016	-0.060
	(0.049)**	(0.051)	(0.027)	(0.026)**
No. of observations	4,946	5,494	4,946	5,494

Note: Each statisic comes from a separate IV-FE regression with the same controls as in Table 2 on half of the sample which is split according to median firm size, location or median age. ***, **, * denote significance at 1%, 5%, and 10% level. Standard errors are clustered at firm level.

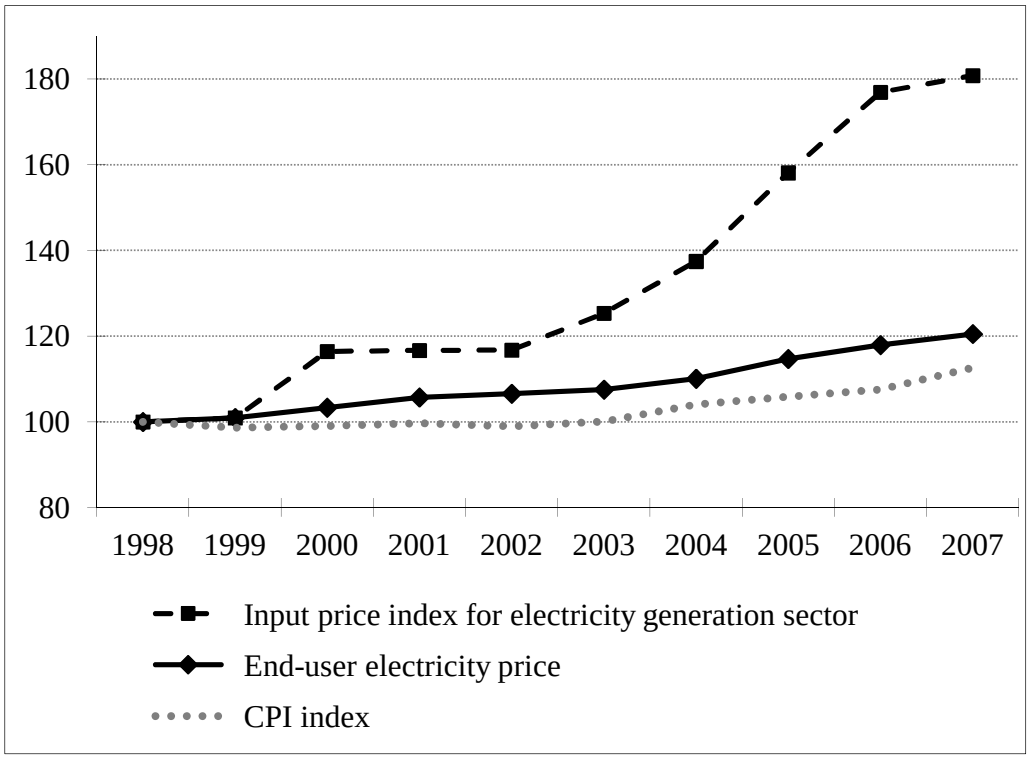
Table 6: Productivity difference in the cross-section of firms

	State-owned firms mean	IPPs mean	Difference in means (st. error)
(a) All active firms in 2002			
ln(Employment/Revenue)	-5.035	-5.780	0.745
			(0.085)***
ln(Material/Revenue)	-0.347	-0.350	0.003
			(0.027)
Employment use (adjusted)	4.717	4.145	0.572
			(0.071)***
Material use (adjusted)	0.706	0.672	0.035
			(0.021)*
Number of observations	369	654	
(b) New entrants (after the reforms) in 2007			
ln(Employment/Revenue)	-7.338	-6.728	-0.611
			(0.194)***
ln(Material/Revenue)	-0.369	-0.329	-0.040
			(0.046)
Employment use (adjusted)	3.907	3.721	0.187
			(0.099)*
Material use (adjusted)	0.402	0.442	-0.040
			(0.049)
Number of observations	56	329	
(c) Firms classified as treated (state-owned in 2002) in 2005			
ln(Employment/Revenue)	-5.702	-5.828	0.126
			(0.192)
ln(Material/Revenue)	-0.344	-0.393	0.049
			(0.064)
Employment use (adjusted)	4.864	4.489	0.375
			(0.142)***
Material use (adjusted)	0.596	0.479	0.118
			(0.047)***
Number of observations	183	61	

Note: ***, **, * indicates significance at 1%, 5%, or 10% level.

Appendix

Figure A.1: Price indices for electricity, fuel, and general consumer prices



Source: National Bureau of Statistics, http://www.stats.gov.cn

Table A.1: Input demand equations with time-varying restructuring effects)

Dependent Variable:	ln(EMPLOYMENT)				ln(EXPENDITURE)			
	FE - basic		FE - IV		FE - basic		FE - IV	
ln(REVENUE)	0.237***	(0.008)	0.186	(0.194)	0.878***	(0.006)	0.901***	(0.123)
ln(WAGE)	-0.271***	(0.008)	-0.262***	(0.035)				
YEAR1999	0.026	(0.018)	0.027	(0.019)	-0.001	(0.014)	-0.002	(0.014)
YEAR2000	0.000	(0.019)	-0.003	(0.024)	-0.113***	(0.014)	-0.112***	(0.016)
YEAR2001	-0.003	(0.020)	-0.002	(0.019)	-0.063***	(0.015)	-0.064***	(0.015)
YEAR2002	-0.014	(0.020)	-0.010	(0.023)	-0.035**	(0.015)	-0.038*	(0.020)
YEAR2003	-0.015	(0.020)	-0.006	(0.037)	-0.081***	(0.015)	-0.086***	(0.032)
YEAR2004	-0.036*	(0.020)	-0.026	(0.038)	-0.079***	(0.015)	-0.086**	(0.035)
YEAR2005	-0.060***	(0.021)	-0.048	(0.044)	-0.147***	(0.016)	-0.154***	(0.039)
YEAR2006	-0.067***	(0.022)	-0.050	(0.061)	-0.228***	(0.016)	-0.237***	(0.052)
YEAR2007	-0.073***	(0.023)	-0.052	(0.078)	-0.216***	(0.017)	-0.227***	(0.065)
RS*YEAR1999	-0.018	(0.028)	-0.017	(0.029)	-0.023	(0.021)	-0.019	(0.022)
RS*YEAR2000	-0.012	(0.028)	-0.008	(0.029)	-0.020	(0.022)	-0.016	(0.022)
RS*YEAR2001	0.012	(0.027)	0.012	(0.028)	-0.032	(0.021)	-0.028	(0.021)
RS*YEAR2002	-0.007	(0.027)	-0.011	(0.027)	-0.038*	(0.020)	-0.033	(0.023)
RS*YEAR2003	-0.027	(0.028)	-0.027	(0.037)	-0.043**	(0.021)	-0.040	(0.032)
RS*YEAR2004	0.001	(0.030)	0.002	(0.045)	-0.050**	(0.023)	-0.047	(0.040)
RS*YEAR2005	-0.068**	(0.031)	-0.070	(0.044)	-0.083***	(0.023)	-0.079**	(0.040)
RS*YEAR2006	-0.068**	(0.032)	-0.079*	(0.044)	-0.082***	(0.024)	-0.077*	(0.041)
RS*YEAR2007	-0.075**	(0.033)	-0.088*	(0.053)	-0.094***	(0.025)	-0.084*	(0.050)
Observations	10,831		10,792		10,831		10,792	

Note: Labor demand and material input demand estimated using year- and firm-fixed effects (FE-basic) and additionally instrumenting log(REVENUE) with total manufacturing output and employment in a firm's region (FE-IV). The following controls for unobserved prices are included, but not reported: interaction terms of fixed assets, fraction of state-owned capital, and provincial dummies. Standard errors in parenthesis are clustered at the firm level. ***, **, * denotes significance at the 1%, 5%, and 10% level.