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European Electricity Market Reforms: Any Signs of Efficiency Improvements?

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Abstract

This paper investigates whether European electricity market reforms have induced any changes in firm efficiency either through productive, allocative or dynamic efficiency improvements. In particular, this ex-post analysis looks closely at productivity effects of changing industry structure, ownership structure and regulation with respect to barriers to entry and access to wholesale and retail markets. Based on the European firm-level data for the period 1996-2007, the results indicate sluggish productivity improvements of European electricity firms due to reforms implemented in the last decade. In particular, productivity gains are associated with high-productivity firms close to the technology frontier, while no significant impact is found for the laggards. Looking from a dynamic perspective, it seems that the closest are the firms to the frontier the more they are able to improve productivity in response to liberalization efforts stimulating competition.

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Keywords: EU electricity market reforms; firms; productivity; regulation; TFP

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1 Introduction

An effective regulation is designed to correct the market failures without distorting the incentives of market participants. In particular, European electricity industry has undergone a re-design of industry structure, ownership structure and pricing mechanisms, with an ultimate goal of limiting abusive use of market power and providing incentives for productivity improvements of firms (Commission (2007a), Commission (2007b)). Within this context, the European Commission initiated the step-wise directives in the mid-nineties bearing in mind that a certain degree of regulation is needed to provide secure and safe supply of electricity to industrial and final consumers (Commission (2007a), Commission (2007b)). If successfully implemented, the reforms could improve firm utilization of production inputs, induce efficient allocation of resources towards high-productivity firms or provide incentives for shifting technology frontiers through innovation process.

The effectiveness of market reforms in terms of productivity improvements has been widely recognized in the institutional literature as a potential catalyzer of economic growth since the Lisbon Agenda on Growth (Sapir and et al. (2003)). Unlike the market-based instruments, the product market regulation may not give the firms sufficient incentives to outperform whatever standard is set for them. A well-designed regulatory change should therefore ideally enhance the competitive pressure in the market, improve managerial behavior by rewarding efficiency gains and induce firm dynamics and resource allocation by confronting less-efficient firms with the choice of exit or cost reduction to the level of more efficient electricity competitors (Griffith et al. (2006) and Fabrizio et al. (2007)).

In this paper, European firm-level data are used to empirically investigate the growth impact of European electricity reforms. The working hypothesis is that the effective reforms stimulate competition and ultimately lead to productivity improvements. In particular, I consider the effect of competitive pressure induced by the EC Electricity Directives. I further exploit detailed location-specific and firm-specific data to construct the counterfactual measures of the regulatory change. I take a further look at the productivity changes related to industry structure, ownership structure and stringency of existing local regulation with respect to barriers to entry and access to wholesale and retail markets.

The empirical results give some interesting insights. They indicate that EC liberalization efforts are merely associated with productivity improvements of productive firms, while there is hardly any evidence on improvements of the laggards. Consistent with the study by Fabrizio et al. (2007) on the effects of restructuring on productivity of US firms, I find that modest productivity improvements are related to within-firm productive efficiency rather than reallocation of resources across firms. Joskow (1997) discusses that while the most significant savings from restructuring are likely to be associated with efficient long-run investments in new capacity, there may be opportunities for modest productivity improvements of existing electricity firms in the mid-term. As argued by Jamasb and Pollitt (2005), productivity of electricity firms has increased, while their profits in the more competitive markets seem to have declined, reflecting continued excess capacity.

The paper proceeds as follows. Next section summarizes the theoretical literature on regulation and productivity. The third section discusses the productivity estimation techniques, describe the data and define the measures of regulatory reforms. The fourth section formulates a regression model to evaluate the effect of European electricity market reforms on productivity of firms and present the results. The fifth section concludes.

2 Theoretical Linkages: Regulation and Productivity

The European electricity industry has been in many European countries dominated by vertically integrated firms. These firms have mostly operated as state-regulated monopolists that managed the entire supply chain from generation, transmission to distribution of electricity within their localized geographic market (Joskow (1997), Jamasb and Pollitt (2005)). The electricity has been considered as a largely homogenous product, since the location-specific prices have been mostly determined by the country regulators based upon the firms' accounting costs of electricity provision (Commission (2007a) and Commission (2007b)).[1] As demonstrated by Laffont and Tirole (1993), such regulation limits the rents rather well, but it is not effective in providing incentives for cost-minimizing production, since the costs are directly passed through to consumers. Laffont and Tirole (1993) show that replacing inefficient regulation with market-based reforms promoting competition could correct the lack of incentives and enhance productivity of firms.

The beneficial effects of the regulatory change do not appear instantaneously. Joskow (1997) argues that while the most significant savings from restructuring are likely to arise from efficient long-run investments in new capacity, there may still be opportunities for modest reductions in operating and material costs of existing stock of electricity firms, particulary for more technologically advanced firms. Consistent with his view, Fabrizio et al. (2007) find modest medium-term productivity benefits of replacing stringent regulation with market-based reforms in California's electricity market. Their paper largely motivates this study, which attempts to measure the extent of that possible improvement for European electricity firms.

In the context of within-industry firm heterogeneity, the recent theoretical models suggest different ways through which the regulatory change can affect the firm-level productivity. Given these multiple channels, the backbone literature puts in front the effects on productivity of incumbent firms and the effects operating through firm dynamics and reallocation of resources towards highly productive electricity firms. As recently discussed by Arnold and Scarpetta (2008) and Griffith et al. (2006), it is not beforehand clear whether productivity changes are channeled through productive, allocative or dynamic efficiency improvements by firms.

2.1 Productive Efficiency

Pilat (1996) defines productive or technical efficiency as the firm capacity to reshuffle its own resources more effectively to improve their utilization in the production process. As discussed in the literature among others by Winston (1993), Nickell et al. (1997) and Aghion and Howitt (1998), the incentives for productive efficiency improvements arise through different channels. Most commonly the effects of regulation on incumbent firms are linked to changes in their productive efficiency associated with the use of production inputs, organizational structure and firm incentives for investment and innovation efforts aimed at reaching the frontier production techniques. Considering closely the electricity industry, Fabrizio et al. (2007) take into account the above considerations and provide the first substantial analysis of efficiency gains from electricity restructuring guided by the economic intuition discussed below.

The static cost-minimization by firms is expected to stimulate firm productive efficiency in the neoclassical models. The cost-reducing improvements are likely to raise more sales and profits in competitive markets due to a higher price elasticity of demand compared to oligopoly scenarios

[1] In the empirical analysis, I exploit the spatial and temporal variation across European electricity markets to assess the effectiveness of the EC Electricity Directives in terms of productivity.

(Hart (1983), Nalebuff and Stiglitz (1983), Aghion and Howitt (1998). Nickell (1996) finds the empirical support to this theory. He uses a panel of UK manufacturing firms to estimate production functions that include controls for the competitive environments. He finds strong support for higher productivity growth rates in more competitive environments where firms exhibit lower markups. The evidence by Nickell (1996) suggests that firms might first respond to enhanced competition by lowering their markups, while substantial productivity effects are expected to occur in the longer run as discussed by Joskow (1997). The firms may not minimize costs in less-competitive or regulated environments due to agency costs and the effort-averse labor. The principal-agent models expose the incentive effect on managers to structure the work environment efficiently (see e.g. Griffith and Harrison (2004) and Fabrizio et al. (2007)). Laffont and Tirole (1993) show that market failures are intensified in circumstances where prices are set by asymmetrically-informed regulators. The market-based reforms promoting competition would improve the market transparency by creating greater opportunities for comparing performance of each firm's production inputs relative to its competitors.[2] Empirical studies of regulatory reforms in the electricity industry suggest that policy-makers are motivated by rent-seeking, however, the advocates of restructuring argue that exposing utilities to market-based outcomes would yield productive efficiency gains that could ultimately reduce electricity costs and retail prices (White (1996) and Joskow (1997)).[3] As discussed by Fabrizio et al. (2007), competitive retail and wholesale markets can further stimulate productivity of firms. The firms have incentives to improve their productive efficiency, if customers are able to switch among different suppliers. Retail access reforms together with the creation of the wholesale organized markets can increase the intensity of cost-minimizing incentives leading to greater productive efficiency.[4]

Pulling together the views on cost reduction and capital deepening, Joskow (1997) argues there may be opportunities for modest reductions in operating costs of incumbents in the short run only for the advanced firms, but substantial savings from restructuring are likely to appear only in the long-run, provided that regulation gives incentives for investments in new capacity. Comparing various industries, Blanchard and Giavazzi (2003) consider the role of capital formation in relation to productivity and regulatory environments. Lighter regulatory burdens are expected to lower the costs of capital stock adjustments and facilitate the expansion of firm productive capacity. The recent theoretical and empirical literature finds very little support on the capital deepening channel. Poschke (2006) shows that stringent regulations in Europe have inclined firms' technology choice towards higher capital intensity than in the US. This can represent an entry barrier protecting low-productivity incumbents, which in turn reduces total factor productivity as discussed by Arnold and Scarpetta (2008). Griffith et al. (2006) show that product market regulation tends also to lower employment, which puts ambiguity on the net effect of reforms on productivity through provision of investment incentives. In the European electricity industry, it is expected that the firms may

[2]Managers would have greater incentives to increase their efforts, because the possibility of bankruptcy is higher in a competitive environment. Furthermore, competition under the rent-sharing scenario can also influence the effort of workers who expect to capture a part of market rents through a slack or wage increase (Haskel and Sanchis (2000)).

[3]The research on other industries also suggests productivity gains associated with the regulatory change, as for example the research by Olley and Pakes (1996) on the telecommunications equipment industry.

[4]For example, the operating wholesale markets would allow electricity firms to sell either through spot markets or long-term contracts based on expected spot prices. In the spot markets, the firm owners submit bids indicating the prices at which they are willing to supply power from their plants. Dispatch order is set by the bids and the bid of the marginal plant is paid to all plants that are dispatched. Less productive high-cost plants will be forced down in the dispatch order, reducing expected revenue or eventually closing their facility. Plant operators that reduce costs can move higher in the dispatch order to increase dispatch probability and increase profit margin between the own costs and expected market price (Fabrizio et al. (2007) and Borenstein et al. (2008)).

improve their mid-term productivity through better organization of labor or reduction of material intensity, while large shifts in the long-run are more likely to follow large capital investments.

2.2 Reaching the Technology Frontiers

In view of current climate-change negotiations, the electricity industry would eventually have to reduce the material intensity and improve efficiency of electricity provision by investing in new technologies (Commission (2007a), Commission (2007b)).[5] Aghion et al. (2009) argue that policy-makers should do more to encourage innovation and investment in low-carbon research and development. The long-run incentives for capital investments are linked to the measures promoting innovative efforts and competitive pressure stimulating firms to approach technology frontiers. Linking innovation to productivity, Aghion and Griffith (2005) provide an exhaustive survey of the recent theoretical and empirical literature and expose two main effects.

The escape competition effect is associated with the innovation requirement for incumbents to preserve their pre-innovation rents when faced with the possibility that their competitors innovate. The appropriability effect by contrast refers to the sufficient level of post-innovation rents expected by the innovating firms. Aghion and Griffith (2005) and Aghion et al. (2005) argue that when competitive pressure increases, the innovation incentives of incumbents are predominantly determined by the perceived difference between both types of effects, that is, the net difference between pre- and post-innovation rents.

The relationship between innovation, productivity and competitive pressure is thus likely to be hump-shaped. On the one hand, competition encourages high-cost firms to innovate to prevent dissipation of their market shares to low-cost rivals as shown by Aghion and Schankerman (2004). On the other hand, if competition strengthens sufficiently to reduce post-innovation rents, the incumbents cease to innovate. Aghion and Howitt (2006) discuss the so-called discouragement effect, referring to the situation where the positive escape competition effect on incumbents' innovative efforts is stronger for the firms near the technological frontier than for the firms lagging far behind. This suggests that I should consider the firm's distance to frontier and the pace of its catch-up process to the frontier in the regression model.[6]

2.3 Reallocation of Resources

An exit of less efficient electricity firms is a clear efficiency benefit of deregulation promoting competition (Fabrizio et al. (2007)). The total production cost for a given output level declines due to the output shift from high-cost firms to low-cost competitors. The availability of micro-level data facilitated the firm-related research addressing the neo-Schumpetrian view on creative destruction associated with reshuffling of resources from low-productivity to high-productivity firms. Heterogeneous firms are seen to be continuously evolving in terms of organizational structures and

[5] The EU is committed to reducing its overall emissions to at least 20% below 1990 levels by 2020. On 23 January 2008 the European Commission put forward a far-reaching package of proposals that will deliver on the European Union's ambitious commitments to fight climate change and help transforming Europe into a low-carbon economy and increasing its energy security.

[6] Arnold and Scarpetta (2008) discuss that certain market distortions can weaken the selection process at entry and exit leading to less systematic differences between incumbent and new firms. By contrast, institutional measures promoting competition and market opening provide incentives and opportunities for incumbents to upgrade their technologies to reach the technology frontiers (e.g. see Amiti and Konings (2007) on the beneficial role of imported inputs on productivity of incumbents).

production techniques to gain market shares or simply survive (Bartelsman et al. (2004)).[7]

Bartelsman et al. (2004) argue that the inappropriate regulations may influence the firm dynamics through selection and learning effects. Olley and Pakes (1996) provide empirical evidence of this phenomenon in their plant-level analysis of the US telecommunications equipment industry. They find substantial increases in productivity related to increased competition that followed deregulation in this sector. They identify the re-allocation of output from less productive to more productive plants across firms as an important source of these gains. More recently, Hortascu and Syverson (2008) also finds that more competitive local markets exhibiting lower markups in the concrete industry are related to the exit of less-efficient plants as evident from higher average productivity and less dispersion in plant productivity. By contrast, the inappropriate and stringent regulations that induce market frictions by raising entry, exit or adjustment costs are expected to reduce aggregate productivity.[8]

3 Empirical Analysis

The empirical analysis takes a closer look at the balance between productive and allocative efficiency of the electricity firms. Consistent with Fabrizio et al. (2007), little firm dynamics is expected within the electricity industry, since reallocation effects are less likely in presence of market entry barriers. By contrast, I expect that modest changes in productive efficiency may occur due to reforms in European electricity industry. Moreover, I investigate whether they affect heterogeneously the firms depending on their productivity ordering. Aghion and Howitt (1998) and Konings and Vandenbussche (2008) find that the firms respond differently depending on their position in the catch-up process towards the technological frontier. The latter finding motivates the empirical setup in which considers initial productivity of firms depending on their distance from the technology frontier. Consistent with the literature above, I consider that outward shifts of the technological frontier may influence the productivity of catch-up firms, which are expected to exhibit strong productivity growth on their transitional path towards the frontier and react heterogeneously to reforms.

3.1 Estimating Productivity

Total factor productivity of firms can be assessed by estimating whether a firm is maximizing output given its production inputs and whether it is using the best mix of inputs given their relative prices. Production functions describe the technological process of transforming inputs to outputs and a firm is considered efficient if it is on the production frontier (Fabrizio et al. (2007)). The literature most commonly describes firm i's technology by a Cobb-Douglas production function (e.g. Konings and Vandenbussche (2008))[9]:

[7] The terms firm dynamics and reallocation of resources are at the heart of the neo-Schumpetrian models of endogenous growth. Looking at the aggregate country perspective, Acemoglu et al. (2005) show that countries lagging behind the global technology frontier can promote productivity through the technological catch-up by adopting leading technologies available on the market. The main feature of their model is that the productivity growth depends both on the ability to catch-up and ability to innovate or adopt leading technologies.

[8] In a similar vein, Bernard et al. (2003) and Melitz (2003) emphasize the role of external trade barriers influencing the product market competition, while Melitz and Ottaviano (2008) and Del Gatto et al. (2006) find that lowering internal product market barriers could matter even more for productivity than removing external barriers. In their models with heterogeneous firms, opening markets to competition generates a reallocation of resources in favor of more productive firms. That is, the exit of low-productivity firms and the expansion of high-productivity firms lead to an increase in aggregate productivity growth.

[9] Van Biesebroeck (2003) and Fabrizio et al. (2007) in contrast to most of the literature use an alternative specification to a Cobb-Douglas function that decomposes the output into actual and probable outputs to consider

$$y_{it} = \alpha_i + \beta_l l_{it} + \beta_m m_{it} + \beta_k k_{it} + w_{it} + u_{it} \tag{1}$$

where y_{it} denotes the log of annual operating revenues at the firm-level, deflated by 3-digit electricity industry-specific producer price indices, l_{it} denotes the log of labor, m_{it} denotes the log of material and k_{it} denotes the log of real capital measured by fixed tangible assets deflated by a capital deflator.[10] The error term includes the firm-level productivity term w_{it} and and an i.i.d. component u_{it} that reflects unexpected deviations from the mean due to a measurement error, unexpected delays or other external circumstances as noted by Van Beveren (2007).

In the baseline model, I use the Solow (Solow (1957)) residual to estimate productivity. The output-based Solow residual is defined as a difference between the growth rates of output Δq_{it} and weighted inputs $\alpha_{Iit}\Delta I_{it}$. More formally, the Solow residual can be expressed as:

$$SR_{it} = \Delta q_{it} - \sum_{I} \alpha_{Iit}\Delta I_{it} \tag{2}$$

where the share of inputs (I_{it}) in total revenues ($P_{it}Q_{it}$) is denoted by $\alpha_{Iit} = \frac{F_{Iit}I_{it}}{P_{it}Q_{it}}$ with the letters F and P representing input and output prices. The advantage of this method is that the input coefficients are computed. For example, it does not infer any assumptions about investment and productivity as the Olley and Pakes (1996) method. However, to address the sensitivity of the baseline model, I consider several parametric and semi-parametric approaches commonly used in the literature to estimate productivity. In contrast to the baseline model, the coefficients of production inputs in Eq. (1) are estimated using different approaches. Based on these estimates, the log of TFP for firm i at time t (tfp_{it}) is then calculated as the residual of the production function:

$$tfp_{it} = y_{it} - \widehat{\beta}_l l_{it} + \widehat{\beta}_m m_{it} + \widehat{\beta}_k k_{it} \tag{3}$$

One of these alternative methods is a commonly used semi-parametric approach developed by Olley and Pakes (1996) to estimate the coefficients of production inputs, which addresses the endogeneity concerns regarding the simultaneity and selection bias. In other words, this method considers the possibility that the input choices are correlated with output and that the estimates may be subject to the selection bias, if exit decisions are driven by unobserved productivity shocks.[11] The selection issue is addressed by considering firm-level survival probability.[12]

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that inputs can be determined in advance of output realizations. In the case of Fabrizio et al. (2007), a Leontief production function captures both actual and probable output, where probable output is further described by a Cobb-Douglas production function. I do not have such detailed data and due to their limitation I follow the more standard approach in the literature assuming a Cobb-Douglas production function.

[10] The capital price deflator is country-specific and is retrieved from the Annual macro-economic database (AMECO) of the department of Economic and Financial Affairs of the European Commission. The data are explained in more detail in Data Appendix.

[11] As shown in the next sub-section, the firms in the sample are more stable than those studied in other contexts, e.g. by Olley and Pakes (1996). Exit in the sample is relatively rare within the range of 2 percent across all years. This suggests that the selection problem may be somewhat less severe for electricity firms in the sample.

[12] Van Biesebroeck (2007) shows that a semi-parametric method like the Olley-Pakes method is the least sensitive to measurement error when estimating productivity. The importance to address these issues have not only be raised for the case of electricity sector (e.g. by Fabrizio et al. (2007)), but also for the other sectors. **?**, Van Biesebroeck (2007) and Van Biesebroeck (2008) discuss in more detail this issue and compare the advantages and disadvantages of different methods. While the application of the method depends to some degree on its purpose, these authors argue that Olley and Pakes (1996) approach comes among the closest to the real observed productivity. As discussed by Fabrizio et al. (2007), there has been several papers estimating production functions for electricity firms, e.g. Knittel (2002), but until Fabrizio et al. (2007) none of them considered explicitly the possibility of simultaneity and selection bias.

The advantages and disadvantages of different productivity measures have been widely discussed in the literature. Therefore, a particular effort is made in this paper to verify the accuracy of the results by comparing different methods. Until Fabrizio et al. (2007), the production functions for electricity firms have been typically estimated with the ordinary least squares (OLS) or stochastic frontier estimation (SF) techniques. Knittel (2002) studies linkages between different incentive regulations and firm productivity and applies the OLS and stochastic frontiers to estimate Cobb-Douglas generating plant production functions in capital, labor and materials for a panel of US plants over 1981-1996. Similarly, Hiebert (2002) uses stochastic frontiers to estimate generation plant efficiency over 1988-1997, treating all inputs as orthogonal to productivity shocks. Hiebert (2002) models plant inefficiency as a function of several variables, including indicators for state regulatory or legislative enactment of utility restructuring in certain years.[13]

Van Biesebroeck (2007), Van Beveren (2007) and Konings and Vandenbussche (2008) discuss the relevance of the omitted price bias. Most commonly in the literature, the industry-level prices are applied to deflate firm-level inputs and output due to unavailability of firm-level prices. If electricity would have been perfectly homogeneous product supplied at the same price within a localized market, then deflating firm-level nominal revenues with an industry-wide price deflator would be appropriate (which to a certain degree is true for European electricity industry). The literature deals differently with this issue. Konings and Vandenbussche (2008) analyze the evolution of unit values for various manufacturing products along their productivity estimates. Their results clearly show that the productivity improvements are largely due to policy measures and not due to a price effect. Mairesse and Jaumandreu (2005) directly evaluate the magnitude of price bias, since they have individual firm-level prices. They find that whether output is deflated with an industry-level price index, individual firm-level price index or not at all makes little difference for the estimated coefficients in the production function. This suggests that the ordinary practice of deflating output measures by 3-digit industry-level price indices when estimating production functions is an acceptable approach, as argued by Konings and Vandenbussche (2008).[14]

The choice of the alternative methods to estimate TFP is guided by valuable comparative studies by Van Biesebroeck (2007) and Van Beveren (2007). The OLS can lead to biased productivity estimates, caused by the endogeneity of input choices or selection bias. The OLS ignores the simultaneity of unobserved productivity and input choices, which leads to upwardly biased parameter estimates in the production function. Although Eq. (1) can be estimated using OLS, this method requires that the production inputs are exogenous, that is, determined independently from the firm's efficiency level. Van Biesebroeck (2007) and Van Biesebroeck (2008) argues that if a firm has prior knowledge of productivity at the time input decisions are made, endogeneity arises since quantities of inputs are partly determined by prior beliefs about productivity (as first shown by Olley and Pakes (1996) and later by Ackerberg et al. (2006)).

Stochastic frontiers make explicit assumptions on the underlying distribution of productivity and are likely to be most sensitive to the exact modeling of productivity in the data generating process, as shown by Van Biesebroeck (2007). Overall, the results for SFE tend to be worse

[13] Both papers find productivity improvement related to the regulatory change regardless of the technique used. The results by Knittel (2002) suggest productivity gains in the range of 1-2 percent associated with the electricity reforms.

[14] The most recent literature, e.g. Ornaghi (2006) and Katayama et al. (2005), suggests that the magnitude of price bias varies across different approaches used to estimate productivity. Ornaghi (2006) has the firm-level prices and argues that the use of industry indices to deflate nominal revenues and expenditure in intermediary inputs leads to lower scale estimates of the production function. Katayama et al. (2005) similarly argue it is important to consider the prices of production inputs in productivity estimation techniques. However, the time-series of electricity price data are not publicly available and unfortunately I cannot explicitly address this potential bias.

Table 1: Summary statistics, consolidated firms with subsidiaries

	1997-2007	1997-2002	2003-2007
Number of firms	126	94	146
	(0.94)	(1.35)	(0.48)
Employment	2399	1896	2704
	(350)	(279)	(535)
Revenues (log)	16.22	15.81	16.47
	(0.06)	(0.10)	(0.07)
Capital costs (log)	11.36	11.01	11.57
	(0.07)	(0.12)	(0.08)
Labor costs (log)	9.37	9.09	9.54
	(0.06)	(0.11)	(0.07)
Material costs (log)	15.33	14.85	15.63
	(0.07)	(0.11)	(0.08)
Capital intensity	649	595	681
	(34)	(52)	(44)
Returns on total assets	4.68	4.20	4.98
	(0.16)	(0.26)	(0.20)
Exit rate (%)	1.40	0.95	1.76
	(0.38)	(0.47)	(0.58)

Notes: Mean values of variables are reported with standard errors in brackets. The dataset is unbalanced panel with the number of firms varying over years. Employment refers to number of employees. Key variables for estimation of productivity are reported in logarithms. Capital intensity (K/L) refers to total fixed assets over the number of employees. Regarding the representativeness of the dataset, the firm-level data correspond closely to comparable aggregated data by Eurostat (2008) as the firm-level data on average cover 95% of the aggregate data in terms of employment and 92% in terms of revenues.

for either the Olley-Pakes (OP) or general method of moments (GMM) estimators, which have their particular advantages.[15] The bottom line is that the choice of the method is not without ambiguity, since the most accurate parametric methods in one situation can be among the least reliable in another situation, as reckoned by Van Biesebroeck (2007). In what follows, I present the productivity estimates and briefly discuss differences across the methods used in robustness checks.

3.1.1 Preliminary Evidence from the Firm-Level Data

Total factor productivity is estimated with the firm-level data on European electricity industry, distinguishing between electricity generating, transmitting and distributing firms. The dataset is constructed on the basis of a commercial database Amadeus that was collected by the consultancy Bureau van Dijk (van Dijk (2009)). The database consists of annual company accounts reported to national statistical offices for companies located in European countries. The advantage of using the company-accounts data is that firm heterogeneity can be addressed to a certain degree when investigating the role of regulatory measures for productivity. Table 1 reports the summary statistics on the main variables describing firm characteristics used in the analysis. Data Appendix describes in more detail the definitions and measurement issues of the variables.

The sample contains virtually the entire population of medium and large firms in the electricity

[15] The GMM technique gives more consistency than OP, but OP has its strongest points. Van Biesebroeck (2007) and Van Biesebroeck (2008) demonstrates that the OP productivity estimates are extremely accurate in the absence of fixed effects.

Table 2: Estimates of production function

	Estimates of production factors			TFP index (1996=100)		
	Labor	Materials	Capital	Total	Period 1	Period 2
	(ßl)	(ßm)	(ßk)	(96-07)	(96-02)	(03-07)
Baseline model						
SR	0.2312	0.5138	0.1675	1.02	1.01	1.03
	-	-	-			
Robustness checks						
OP	0.3576	0.3553	0.0970	1.02	1.01	1.04
	(0.0766)	(0.0773)	(0.0145)			
OLS	0.3304	0.4765	0.1051	1.00	0.99	1.01
	(0.0637)	(0.0674)	(0.0612)			
SFE	0.3650	0.3669	0.1163	1.02	1.01	1.03
	(0.0183)	(0.0117)	(0.0141)			
FE	0.3496	0.3406	0.1006	1.02	1.01	1.05
	(0.0730)	(0.0399)	(0.0337)			
GMM	0.3604	0.4630	0.1078	0.99	0.99	1.00
	(0.0292)	(0.0232)	(0.0147)			
LP	0.2887	0.4551	0.1095	1.01	1.00	1.03
	(0.0619)	(0.2210)	(0.2775)			

Note: The values are estimated coefficients with robust standard errors reported in brackets. Inputs of production function are estimated by different parametric and semi-parametric estimation methods for comparison purposes for the same sample of 843 observations over 1996-2007 and across 10 European countries. All estimations include year*activity dummies.

sectors of ten European countries over the period 1997-2007.[16] In particular, the firm-level data on average account for about 95% of the total employment as compared to the aggregated data retrieved from Eurostat (2009). This is an unbalanced sample of firms over time, where the unit of observation is a firm defined as a legal undertaking based in one of the countries of the sample.[17]

The electricity firms have a rather complex organizational structure with a large share of vertically integrated firms having subsidiaries. To pin-down the unit of observation, I consider consolidated accounts of firms, which means that the subsidiaries are included in the financials of parent firms. These firms are large legal entities with relatively high levels of employment, revenues and input costs. The electricity plants are part of a parent company authorized to regionally supply energy. These subsidiaries do not compete with each other as they are region specific. Therefore, market liberalization may not yield significantly different impact for firms within the group of the parent company. That is the reason the plants are aggregated up to the firm level, while identified subsidiaries of plants are taken out of the sample to compare only companies that are in true competition within the markets defined.

Table 2 reports the production coefficients obtained using different methods discussed in the previous sub-section. Following Van Biesebroeck (2007) and Van Beveren (2007), I consider the unbalanced sample that allows for implicit entry and exit of firms and thus omits the sample selection bias. The use of different methodologies results in somewhat different estimates of inputs,

[16] The coverage of Amadeus data before 1996 and after 2007 is not representative for this sector, hence these time series are excluded from the analysis.

[17] The dataset includes ten countries across four major zonal markets, for which sufficient amount of comparable data are available from Amadeus (van Dijk (2009)). The sample includes four zonal markets, which are West European zone including Belgium, Germany, France, the Netherlands and Austria; Iberian zone including Portugal and Spain, Nordic zone including Finland and Sweden; and Italian zone.

Figure 1: Weighted productivity index

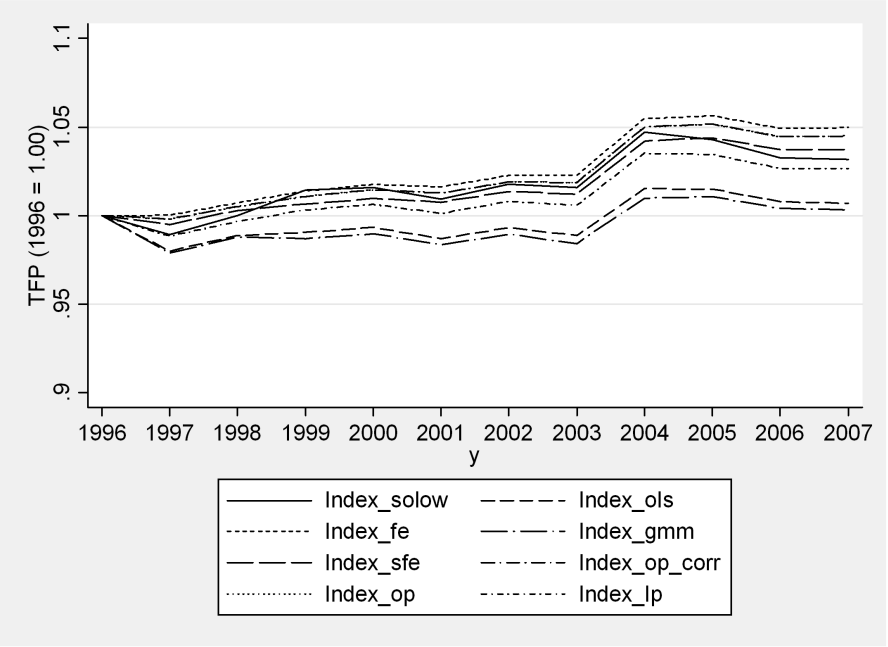
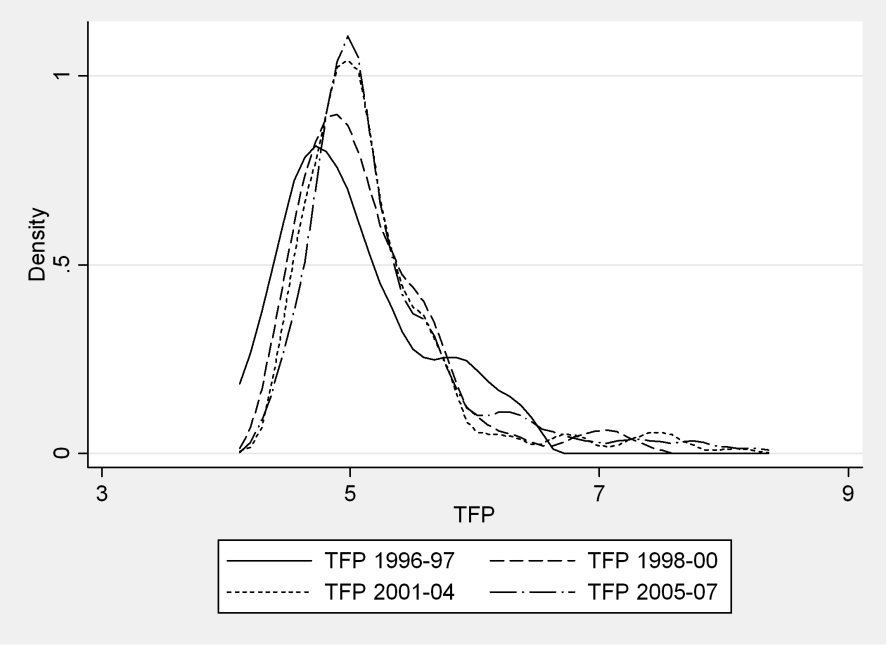


Figure 2: Productivity density function



however, the productivity growth rates are highly comparable across them as shown by Table 2 and graphically presented by Figure 1. The development of total factor productivity index is normalized to 1996 to facilitate a comparison across various methods. The estimated coefficients of production inputs in Table 2 are used to calculate the firm-level productivity for each of the sample years. By imposing the stability coefficients on the model, it is possible to retain the full sample of firms for all estimators (see Van Beveren (2007)).

It comes clear from the fourth column that all methods give highly comparable TFP estimates implying low productivity growth of 1.02 over 1996-2007. For the purpose of the research question, I take a closer look at the period before and after the second EC electricity directive implemented in 2003. The last two columns of Table 2 show modest productivity improvements from average 1.01 before 2003 to 1.03 after 2003. In line with this statistics, regulatory reforms in the European electricity sector are not expected to drive large productivity improvements for all firms. That is why I look further in the data to investigate the role of firm heterogeneity.

Figure 2 gives the insights into productivity distribution across European electricity firms. Density curves are compared at different points in time to assess whether there have been any changes around the implementation of the second EC electricity directive. The overall distribution is skewed to the left, which indicates the prevalence towards weak productivity growth rates, but has a longer right tail indicating cases of high-productivity growth. Interestingly, it seems that the right-tail is growing fatter after the second EC electricity directive in 2003. In light of the previous discussion of the literature, it seems natural to relate these observations to underlying product-market policies that are more or less prone to help sustain fast growing firms within the electricity industry. It is reasonably expected to find stronger productivity effects of reforms for the firms closer to the technology frontier.

The preliminary evidence above suggests that regulation could play a role not only in determination of aggregate productivity in the electricity sector, but also in shaping the distribution of productivity growth rates depending on firm-specific productivity ordering. Before turning to the econometric analysis, I give further insights into productivity decomposition into productive and allocative parts to investigate whether the evolution of aggregate TFP in the electricity sector was due to the firm-level productivity improvements or rather the reallocation of market shares between firms. As discussed by De Loecker and Konings (2006), various decompositions can be used. Similar to Van Beveren (2007), I follow closely the decomposition suggested by Olley and Pakes (1996). The aggregate productivity $\widehat{tfp}_{Jt} = \sum_{i=1}^{N_t} s_{it}\widehat{\Omega}_{it}$ is decomposed into a within component and a covariance term:

$$\widehat{tfp}_{Jt} = \overline{\widehat{tfp}_{it}} + \sum_{i=1}^{N_t}(\Delta s_{it}\Delta\widehat{\Omega}_{it}) \tag{4}$$

where $\overline{\widehat{tfp}_{it}}$ is the unweighed average of plant-level TFP and $\sum_{i=1}^{N_t}(\Delta s_{it}\Delta\widehat{\Omega}_{it})$ refers to the sample covariance between TFP and revenue or employment shares (s_{it}). Table 3 presents the results of applying this decomposition. The first column displays the aggregate productivity $\widehat{tfp}_{Jt}$, the second column displays unweighed average of plant-level productivity $\overline{\widehat{tfp}_{it}}$ and the last two columns refer to the sample covariance term $\sum_{i=1}^{N_t}(\Delta s_{it}\Delta\widehat{\Omega}_{it})$ standing for reallocation effects.

It comes clear from Table 3 that most productivity improvements realized in the electricity industry during 1996-2007 are related to within firm productivity growth that is expressed in

Table 3: Decomposition of total factor productivity

	Weighted aggregate productivity (1) [1996=1]	Unweighted average productivity (2) [% of (1)]	Reallocation (Sample covariance term) (3) [% of (1)]	(4) [Growth]
Baseline model, revenue shares				
SR	5.78	89.28	10.72	1.21
Baseline model, labour shares				
SR	5.79	89.12	10.88	1.20
Robustness checks, revenue shares				
OP	6.90	90.57	9.43	1.21
OLS	4.90	93.78	6.22	1.27
SFE	6.31	91.76	8.24	1.19
FE	7.21	90.12	9.88	1.22
GMM	4.74	94.90	5.10	3.52
LP	5.74	91.31	8.69	1.18
Robustness checks, labour shares				
OP	6.82	91.63	8.37	1.19
OLS	4.86	94.85	5.15	1.26
SFE	6.23	93.04	6.96	1.16
FE	7.13	91.12	8.88	1.22
GMM	4.68	96.33	3.67	2.15
LP	5.71	91.98	8.02	1.09

Note: Weighted aggregate productivity is calculated with weights being firm-level revenue or labor shares. Values are averages over 1996-2007. Unweighted average productivity and the sample covariance term are expressed as percentage of weighted aggregate productivity. Mean growth of covariance refers to mean annual growth rate of the sample covariance term over 1996-2007.

percentages of weighted aggregate productivity in column (1). The reallocation effect is somewhat smaller, if the employment shares are used instead of turnover shares. This is rather robust to different methods that yield similar results. The last column of Table 3 suggests an upward trend in the reallocation effect in the order of 1.2. The evidence of low reallocation effects is consistent with Fabrizio et al. (2007) for US electricity industry and was somewhat expected due to low exit rates of around 2 percent in the sample of firms.

3.2 Measures of the Electricity Market Reforms

The literature suggests various approaches to define the measures of regulatory change used in the assessment of the firm-level total factor productivity.[18] Griffith and Harrison (2004), Aghion and Howitt (2006) and Del Gatto et al. (2006) use respectively the EU data on anti-monopoly cases and the implementation of the Single Market Programme to investigate the effect of the regulatory change on productivity of firms. Arnold and Scarpetta (2008) take a step further and use the OECD international product market regulation database (OECD (2009)).[19] As argued by

[18]The firm-level mark-ups cannot be treated as exogenous determinants of productivity developments. For example, very productive firms may gain market shares and extract the rents from less efficient firms. Besides, a few studies have shown that the market indicators of productivity may not be solely associated with product market competition. Aghion et al. (2005) for example shows there could exist a hump-shaped relationship also between the mark-ups and competition. A few papers show that the same reforms can influence on the one hand productivity and on the other hand the markups of firms. Nickell (1996) and Nickell et al. (1997) show regulatory reforms could improve productivity of firms, while they increase competitiveness reflected by lower markups of firms.

[19]These data are described in detail by Conway and Nicoletti (2006).

Arnold and Scarpetta (2008), these indicators provide the largest coverage of sectors and countries along the longest time horizon available for comparing product market regulation across OECD countries.

Conway and Nicoletti (2006) discuss main advantages of the OECD indicators. First, the indicators can be considered exogenous to productivity developments and are directly linked to underlying policies concerning market entry barriers, foreclosure, and other regulatory burdens. Second, these indicators address multi-collinearity problems in the empirical analysis using total factor productivity. Finally, the indicators make it possible to focus on the specific aspects of policies thought to be relevant for productivity. They take continuous values on a scale going from least to most restrictive regulatory governance. In particular, the indicators focus on three key areas influenced by the regulatory reforms in electricity industry, that are, ownership change, entry barriers and regulatory burden in terms of administrative hurdle and regulation of access to networks or unbundling of electricity services. Each of these indicators is based upon the detailed information on laws, rules and market settings for the electricity industry. Importantly for the empirical analysis, the indicators also exhibit sufficient variation across countries and over years.

The above empirical literature motivates the choice of the regulatory variables, which are described in more detail in Data Appendix. In a similar vein as Aghion and Howitt (2006) consider the implementation dates of reforms, I use information on a direct impact of EC electricity directives aimed at promoting competition and integrating European electricity markets. Considering counterfactual measures is difficult, but necessary for validation of the results. I first use the OECD product market regulation indicators for each national electricity market. These variables are shown by Conway and Nicoletti (2006) and Arnold and Scarpetta (2008) to be valid instruments for policy reforms when considering productivity of firms. For the purpose of the empirical analysis, I invert the OECD indices bounded between 0 and 6, so that higher values represent greater competition in the market.

I next propose other variables of electricity market reforms that are shown in the empirical analysis to matter for productivity developments. In particular, I gather information from national statistical sources and the International Energy Agency on the time-varying state of each country's *de jure* and *de facto* use of national legislation and performance of the wholesale and retail markets. I measure *de jure* national policy by the number of years passed since the implementation of the first national Electricity Act. Similarly, I measure *de facto* use of legislation by the number of active years of the national operating authority responsible for regulating and monitoring national electricity markets. The functioning of the national wholesale and retail markets is measured by variables capturing their establishments, operational experience and in the case of retail markets also the degree of customer switching, as explained in detail in Data Appendix.

Liberalization initiatives in Europe have begun in the beginning of 1990s following the launch of the Single European Act.[20] The liberalization process has been extensive in its scope, because it has concerned the largest cross-jurisdictional market for electricity in the world with distinct national legislations. That is why inter-related reforms have been pursued across European Union and within each Member State. Under EU Electricity Market Directives, each Member State was required to implement at least a minimum set of reforms at national level in due time. In parallel, European Commission has promoted a cross-border integration of national electricity markets by invoking the principles of Single Market under which consumers would be free to choose suppliers and the firms could supply the markets of their choice (Green (2006), Jamasb

[20] See the official texts by Commission (2003a), Commission (2003b), Commission (2004)).

and Pollitt (2005)). The objective was to open up national electricity markets and ultimately establish a single European market for electricity. An integrated market would benefit end-users of electricity by lowering prices and improving quality of service, while eventually reducing costs and improving allocation of resources of electricity firms due to fiercer competition.

4 Results

4.1 Impact of Liberalization Efforts on Productivity

In the baseline econometric specification, the impact of the EC Electricity Directive on productivity is estimated with the following regression model:[21]

$$\begin{aligned} tfp_{it} = \alpha_i + \alpha_1 directive_t + \alpha_2 (directive \times dis\tan ce)_{it} \\ + \alpha_3 Z_{it} + \alpha_4 gdp_{ct} + D_t \times G_i + \varepsilon_{it} \end{aligned} \tag{5}$$

where α_i captures the firm-specific fixed effects including all unobservable characteristics between firms that do not vary over time. These effects may be associated with differences in plant technology types, unobserved sunk costs, quality of the managers, and other fixed factors I may not observe (as in Konings and Vandenbussche (2005) and Fabrizio et al. (2007). The year-specific shock α_t measures the efficiency impact of industry-level shifts over time, such as secular technology trends, macroeconomic fluctuations or energy price shocks (as in Fabrizio et al. (2007)).

I include the real GDP growth rates (gdp_{ct}) to proxy for country-level shifts of demand or business cycles. The coefficient α_1 is of the main interest, since it indicates the change of productivity (tfp_{it}) of firm i associated with the regulatory change ($directive_t$). I construct the measure of the EC Electricity Directive in the form of duration variable by the number of years since the imposition of the second EC Electricity Directive in 2003. I consider a sufficient time span before and after the second EC Electricity Directive, which appeared to be stricter than the first EC Directive with respect to harmonization of national legislations.[22]

Motivated by the preliminary evidence, I follow the recent literature (e.g. Aghion and Griffith (2005), Arnold and Scarpetta (2008) and Konings and Vandenbussche (2008) and include the features of a neo-Schumpetrian growth framework to allow for possibility of firms to catch up with the technological frontier. The set of firm-specific controls Z_{it} in Eq. (5) includes four vectors to capture the technological differences and productivity ordering of firms across countries and years. First, "*Leader growth*" in Table 4 represents the growth of the most productive firm in the electricity industry at time t. The estimated coefficient on this variable therefore captures the influence of the annual growth of the country-sector specific leader on the follower firms in terms of productivity, i.e. the outward shifts in the technological frontier.

[21] As common in the literature (see e.g. Levinsohn (1993), Konings and Vandenbussche (2005) , Van Biesebroeck (2007), the estimates are invariant within the same sector or group of firms. It is not possible to estimate the model for each firm individually, because of not having enough degrees of freedom.

[22] This measure has two good properties. First, the pan-European EC Electricity Directive is an exogenous policy shock, since it is implemented regardless of firms' behavior and not influenced by individual firm characteristics or productivity. Second, the duration variable captures the evolution of economic effect over time. The construction of this variable has been inspired by Dewatripont and Roland (1995) and Dewatripont and Roland (1992) suggesting that the economic effects of reforms do not manifest instantaneously, but may be prolonged in time. Particulary in the electricity industry, I expect that the firms cannot adjust their productivity over a very short time span so that potential productivity improvements may occur over medium or long run.

Table 4: Baseline results: Effect of EC liberalization efforts

Dependent variable: Solow residual (SR)	(1)	(2)	(3)	(4)	(5)
Effect of liberalization	0.077	0.042	0.041	0.036	0.030
	(0.036)**	(0.033)	(0.035)	(0.031)	(0.033)
Liberalization * gap to leader	-	-	-0.004	-	-
			(0.001)***		
Liberalization * dummy for catch-up firms	-	-	-	0.010	-
(Above median)				(0.005)*	
Liberalization * dummy for catch-up firms	-	-	-	-	0.015
(Above 80th percentile)					(0.006)**
Gap to leader	-0.019	-0.018	-0.013	-0.019	-0.017
	(0.002)***	(0.002)***	(0.002)***	(0.002)***	(0.002)***
Dummy for catch-up firms (D1)	0.040	-	0.040	0.020	-
(Above median)	(0.017)**		(0.016)**	(0.019)	
Dummy for catch-up firms (D2)	-	0.133	-	-	0.109
(Above 80th percentile)		(0.021)***			(0.023)***
Leader growth	0.018	0.017	0.015	0.018	0.017
	(0.002)***	(0.002)***	(0.002)***	(0.002)***	(0.002)***
Regional proximity	0.947	0.886	0.946	0.945	0.878
	(0.019)***	(0.020)***	(0.018)***	(0.019)***	(0.020)***
GDP	-0.038	-0.041	-0.043	-0.039	-0.045
	(0.018)**	(0.017)**	(0.017)**	(0.018)**	(0.017)***
Year * activity dummies	Yes	Yes	Yes	Yes	Yes
R-sq.	0.710	0.763	0.710	0.711	0.712
Observations	843	843	843	843	843

Note: Standard errors are in brackets. ***,**,* indicate statistical significance at the 1, 5 and 10 percent levels, respectively. Effect of liberalization is measured as years since implementation of the 2nd EC Liberalization Directive in 2003 and 0 otherwise. Dummy for catch-up firms takes value 1 for those firms in each country with above median and above the 80th percentile catch-up towards the frontier during the past year. Gap to the leader measures the distance to the country-sector specific technology frontier. Leader growth measures the influence of the annual growth of the country-sector specific leader on the follower firms in terms of productivity.

Second, "Gap to leader" in Table 4 captures the productivity gap between firm i and the industry leader in country c at year t, which is computed as $gap_{ijt} = tfp_{ijt} - \max(tfp_{jt})$. This variable is motivated by the previous literature suggesting that the larger the distance to the industry-specific technology frontier, the greater the scope for catching up with the catch-up firms exhibiting stronger productivity on the transitional path to the frontier (Aghion et al. (2005), Griffith et al. (2006), Arnold and Scarpetta (2008) and Konings and Vandenbussche (2008)). Third, I include a dummy variable for the firms close to the frontier to indicate the firms that have reduced the gap with the frontier in the same sector-country over the previous year. I use two definitions. The first dummy takes value 1 for the firms with above median catch-up to the frontier and the second dummy takes 1 for the firms in the highest quintile, that is, the ones that are very close to the frontier. Finally, I consider a measure of regional proximity to capture potential positive spillovers in regional clusters of firms.[23]

Table 4 presents the main results, which are presented in two panels. The upper panel shows the results of the main interest, while the lower panel shows the results of other explanatory variables

[23] A particular effort is made to control for potential spatial autocorrelation as the supply of electricity is geographically constrained by the interconnected infrastructure grid and potentially influenced by geographical distance between firms in one region. Hence, the variable regional proximity is a vector of regional weights, which identifies the distance between firms.

Table 5: Robustness checks: Effect of EC liberalization efforts

Dependent variable:	Liberalization	Liberalization	Liberalization
TFP	* Gap to leader	* Catch-up (D1)	* Catch-up (D2)
	(1)	(2)	(3)
Baseline specification			
Solow residual (SR)	-0.004	0.010	0.015
	(0.001)***	(0.005)*	(0.006)**
Robustness checks			
Olley-Pakes (OP)	-0.004	0.012	0.025
	(0.001)***	(0.005)**	(0.005)***
Olley-Pakes without survival corr.	-0.004	0.012	0.025
	(0.001)***	(0.005)**	(0.005)***
Ordinary Least Squares (OLS)	-0.002	0.011	0.026
	(0.001)***	(0.005)**	(0.005)***
Stochastic Frontier Estimation (SFE)	-0.003	0.013	0.027
	(0.001)***	(0.005)**	(0.005)***
Fixed Effects (FE)	-0.004	0.011	0.025
	(0.001)***	(0.005)**	(0.005)***
Generalized Method of Moments (GMM)	-0.002	0.011	0.025
	(0.001)***	(0.006)**	(0.005)***
Levinsohn-Petrin (LP)	-0.003	0.012	0.025
	(0.001)***	(0.005)**	(0.005)***
Year * activity dummies	Yes	Yes	Yes
All other variables as in Table 4	Yes	Yes	Yes
Observations	843	843	843

Note: Standard errors are in brackets. ***,**,* indicate statistical significance at the 1, 5 and 10 percent levels, respectively. Effect of liberalization is measured as years since implementation of the 2nd EC Liberalization Directive in 2003 in (1). Liberalization is interacted with gap to the leader in (2), which measures the distance to the country-sector specific technology frontier. Liberalization is interacted wtih a dummy for catch-up firms takes value 1 for those firms in each country with above median (3) and above the 80th percentile (4) catch-up towards the frontier during the past year.

denoted by Z_{it} in above equation. The estimations of α_2 in Eq. (5) reported in the first row of Table 4 suggest that liberalization efforts have been positively associated with productivity in the range of 8 percent.[24] The negative result (-0.004) for the interaction of liberalization measure and gap to leader (α_3) in column (3) of Table 4 suggests that the effect of EC Electricity Directive on productivity is decreasing with the distance from the frontier. Taking a twisted view on the distance measure, column (4) shows that the positive effect of liberalization in column (1) is driven by firms close to the frontier, while it becomes insignificant for the rest of laggard firms. Comparing the result (0.010) of column (4) with the result (0.015) of column (5), the result of column (3) confirms that the productivity improvements are associated with the firms closer to the frontier and are decreasing with the distance from the frontier. Nonetheless, the orders of magnitude of productivity improvements are low. The results from other explanatory variables are consistent with the previous literature (e.g. Arnold and Scarpetta (2008)). Looking at the results of the lower panel, I find that leader growth is positively related to firm's i productivity, productivity decreases with larger distance from the frontier and the firms closer to the frontier exert stronger productivity on their transitional path in the catch-up process.

[24]This magnitude of this result is higher because I consider the duration variable as a measure of the EC Electricity Directive. However, I have experimented with different measures. In particular, I have also used the dummy variable taking 1 after 2003 and 0 elsewhere and found a positive effect of the order of 3 percent suggesting modest productivity improvements.

Table 4 confirms the preliminary evidence of Table 2 that average productivity in the electricity industry has been only slightly higher in the period after the second EC Directive relative to a period before. The results from interacting the regulatory measure and distance to frontier in columns (3) to (5) of Table 4 confirm the expectations based on Figure 2. Table 4 shows that productivity improvements are associated with the firms close to the frontier. The effect is decreasing with the distance suggesting very limited, if any, improvement in productivity of firms in lower segments of productivity distribution.[25] These results appear to be very robust to various measures of productivity, as shown by Table 5 presenting very similar orders of magnitude across all alternative measures of productivity. Table 5 reports systematically the results across different methods of productivity and verifies the results of Table 4.

4.2 Robustness and Identification Strategy

In this sub-section, I look for counterfactual measures of regulatory reforms to verify that productivity improvements associated with the EC Electricity Directive were not due to a common electricity industry effect prevalent in all European countries.

The reforms are not harmonized across markets and each country keeps its own pace within the context of European-wide electricity directives. The cross-jurisdictional variation in liberalization progress allows us to identify the regulatory change separately from secular changes in productivity over time. I use all available information from the national and external sources to construct the panel of variables consistent with the economic intuition provided by the literature in previous sections.[26]

4.2.1 Location-Specific Measures of Regulatory Change

The baseline model is defined in a similar way as in the previous sub-sections with a variable that captures the effect of the location-specific regulatory change. The regression model is specified as:

$$\begin{aligned} tfp_{it} = \alpha_i + \alpha_1 reform_{jct} + \alpha_2 (reform \times dis\tan ce)_{it} \\ + \alpha_3 Z_{it} + \alpha_4 gdp_{ct} + D_t \times G_i + \varepsilon_{it} \end{aligned} \tag{6}$$

Similarly as in Eq. (5), α_i captures the firm-specific fixed effects including all unobservable characteristics between firms that do not vary over time. The year-sector specific shock $D_t \times G_i$ measures the efficiency impact of industry-level shifts over time, such as secular technology trends, macroeconomic fluctuations or energy price shocks (similar to Fabrizio et al. 2007). The real GDP growth rates (gdp_{ct}) proxy for country-level shifts of demand or business cycles. The coefficient α_1 is of the main interest, since it indicates the change of productivity (tfp_{it}) of firm i associated with the regulatory change ($regulation_{ct}$) in country c at time t.

Table 6 presents the results for a set of four alternative institutional measures given in each horizontal panel to capture the location-specific effects of legal constraints and market access on productivity. Eight different models are estimated to construct Table 6, which consider alternatively either the interaction between institutional measure and gap to leader in (1) and institutional

[25] I experimented by including various catch-up dummies for each quintile of TFP distribution and found that the effect is either statistically insignificant of very low in economic magnitude for the cohorts of firms in the lowest quintile. For brevity reasons, I report only three distance measures in Table 4 that provide sufficient information on the effect along TFP distribution in the sample of firms.

[26] The detailed descriptions of variables and sources are provided in Data Appendix.

Table 6: Baseline results: Location-specific measures of regulatory change

Dependent variable: Solow residual	Institutional measure * Gap to leader (1)	Institutional measure * Catch-up (D2) (2)
National liberalization act		
Main effect	0.264	0.146
	(0.153)*	(0.151)
Interaction effect	-0.019	0.128
	(0.002)***	(0.022)***
Operational authority		
Main effect	0.194	0.088
	(0.081)**	(0.077)
Interaction effect	-0.011	0.132
	(0.009)	(0.021)***
Retail market opening		
Main effect	0.055	0.024
	(0.023)**	(0.024)
Interaction effect	-0.001	0.068
	(0.002)	(0.021)***
Wholesale market opening		
Main effect	0.056	0.016
	(0.026)**	(0.027)
Interaction effect	-0.003	0.074
	(0.002)	(0.020)***

Note: Standard errors are in brackets. ***,**,* indicate statistical significance at the 1, 5 and 10 percent levels, respectively. All specifications include 843 observations and the same other explanatory variables as in Table 4, but are not reported for brevity. Four model specifications are run separately and four different institutional measures take value 1, if the concerned measure is in place and 0 otherwise. Each measure is interacted with gap to the leader in (1), which measures the distance to the country-sector specific technology frontier, and with the catch-up dummy (2) taking 1 for those firms in each country with above the 80th percentile catch-up towards the frontier during the past year.

measure and catch-up dummy in (2), as defined in Table 4. The effect of the regulatory change is captured alternatively by "National liberalization act" dummy in row (1) taking 1, if a country has implemented *de jure* national electricity liberalization act, "Operational authority" dummy in row (2) taking 1, if there exist *de facto* operational authority for enforcement and monitoring implementation of national legislation acts, "Retail market opening" dummy in row (3) taking 1, if consumers are able to switch between electricity providers, and "Wholesale market opening" dummy in row (4) taking 1, if firms can trade electricity at the organized market exchange.

Comparing column (1) to column (2) of Table 6, I confirm the results of Table 4 that the positive effect of liberalization is driven by the firms close to the frontier. The interaction with a catch-up dummy in (2) is strongly significant in all cases. For example, the estimates of column (2) suggest that localized electricity markets supervised by *de facto* operational authority are associated with greater productivity of high productivity firms than in absence of such institution. The orders of magnitude are lower for measures of wholesale and retail market access. While large industrial consumers can switch between different providers, there is still not much progress on the side of household consumers. A very low magnitude of estimates in the last row is consistent with a general perception that organized exchange of wholesale electricity supply is still under-developed in most European countries.[27] These results appear to be very robust with respect to various

[27]Looking further into the issue of market access, the retail market access effect is dominantly driven by the

methods used for productivity measurement, as demonstrated by pair-wise comparisons in Table 7.

To give further insights into more market-specific measures of competition, Table 8 presents the results using the inverted indices from the OECD electricity market regulation data. The results are presented in four horizontal panels, similar to Table 6. I first evaluate the effect of total regulatory burden in the first horizontal panel and find that a reduction of total regulatory burden by one index point is associated with roughly 6 percent higher productivity of firms. As shown by column (1) the effect decreases with distance from the frontier, but it is significant for all firms and not exclusively for high-productivity firms in column (2) of the first panel. Intuitively, a reduction in regulatory constraints such as entry barriers and rigid financial contracts captured by this index improves the efficiency of firms. By contrast, high entry costs or low market access insulate the incumbent firms from the competitive pressure of entry and allow the inefficient firms to survive.[28] Given panels (2) and (3), I find that unbundling of transmission and distribution channels is significantly related to productivity gains and intensifies with the closeness to the frontier, given the negative coefficient on the interaction variable in column (1). Reducing the state ownership in this sectors generates productivity gains for all firms as shown in the last panel of Table 8, consistent with the literature (Damijan et al. (2005), Damijan and Knell (2005)). Table 9 verifies that all these results are not sensitive to the choice of productivity measure, since the orders of magnitude of effects are highly comparable across different methods.

4.3 Sources of Productivity Improvements

In the final part of the empirical analysis, I shed some light on sources of productivity improvements. Similar to Konings and Vandenbussche (2008) I have estimated productivity after considering variation in production inputs, which makes the increase in productivity unlikely due to a scale effect. Besides, the evidence so far has suggested that productivity is likely to arise from within-firm input efficiency improvements of high-productivity firms.

In Table 10, I report the results of the firm-level analysis where I compare the influence of EC Electricity Directive on employment, material costs and gross investment. I investigate whether or not the average firm has had stronger incentives to engage in cost reducing restructuring efforts in its response to a more competitive environment induced by liberalization efforts measured like in Table 4.

Referring to columns (1) and (2) of Table .10, the average firm material costs have been about 7 percent lower for high-productivity firms, but possibly not for the laggards. Comparing this figure to the estimated effect on the labor costs in column (4), I find much lower effect than for

ability of large industrial consumers to switch between electricity providers. I do not find any evidence of small industrial or household switching on productivity. This is in line with the recent reports that wholesale markets are not operating well in most European markets for electricity, moreover, there is little evidence of switching for household and small industrial consumers (Al-Sunaidy and Green (2006), Roeller et al. (2007), Commission (2007a)).

[28] Moreover, Aw et al. (2001) and Aw et al. (2003) discuss that the existence of entry costs nests further implications for the market competitiveness. They use micro panel data for producers in seven two-digit manufacturing industries in South Korea and Taiwan and identify a number of systematic differences in industry structure related to entry costs. Their empirical findings indicate Taiwanese industries are characterized by less concentrated market structure, more producer turnover, smaller within-industry productivity dispersion across producers, a smaller percentage of plants operating at low productivity levels, and smaller productivity differentials between surviving and failing producers. These patterns are consistent with strong competitive pressures in Taiwan that lead to market selection based on productivity differences. The patterns in Korea are consistent with the presence of some impediments to exit or entry that insulate inefficient producers from market pressures. For example, once firms manage to enter they are less likely to exit, because they do not want to re-incur the high entry costs. This in turn explains why there is very little exit in the sample of electricity firms, as discussed in the last robustness check on sample selection.

Table 7: Robustness checks: Location-specific measures of regulatory change

Dependent variable: TFP	National liberalization act		Operational authority		Wholesale market opening		Retail market opening	
	Measure * Gap (1)	Measure * Catch-up (2)	Measure * Gap (3)	Measure * Catch-up (4)	Measure * Gap (5)	Measure * Catch-up (6)	Measure * Gap (7)	Measure * Catch-up (8)
Solow residual (SR)	-0.019	0.128	-0.011	0.132	-0.001	0.068	-0.003	0.074
	(0.002)***	(0.022)***	(0.009)	(0.021)***	(0.002)	(0.021)***	(0.002)	(0.020)***
Robustness checks								
Olley-Pakes (OP)	-0.025	0.148	-0.005	0.149	-0.002	0.081	-0.005	0.087
	(0.002)***	(0.020)***	(0.013)	(0.020)***	(0.003)	(0.019)***	(0.003)*	(0.020)***
Ordinary Least Squares (OLS)	-0.018	0.126	-0.002	0.125	0.001	0.076	-0.001	0.066
	(0.002)***	(0.019)***	(0.018)	(0.019)***	(0.002)	(0.019)***	(0.002)	(0.019)***
Stochastic Frontier Estimation (SFE)	-0.023	0.149	-0.005	0.150	-0.001	0.078	-0.003	0.084
	(0.002)***	(0.021)***	(0.016)	(0.020)***	(0.003)	(0.020)***	(0.003)	(0.020)***
Fixed Effects (FE)	-0.026	0.143	-0.004	0.143	-0.002	0.080	-0.004	0.085
	(0.002)***	(0.020)***	(0.012)	(0.020)***	(0.003)	(0.019)***	(0.003)	(0.020)***
Generalized Method of Moments (GMM)	-0.017	0.119	0.003	0.117	0.001	0.075	-0.001	0.048
	(0.002)***	(0.019)***	(0.024)	(0.019)***	(0.002)	(0.019)***	(0.002)	(0.020)**
Levinsohn-Petrin (LP)	-0.020	0.141	-0.008	0.144	-0.000	0.077	-0.003	0.078
	(0.002)***	(0.020)***	(0.012)	(0.020)***	(0.002)	(0.019)***	(0.002)	(0.020)***

Note: Standard errors are in brackets. ***,**,* indicate statistical significance at the 1, 5 and 10 percent levels, respectively. All specfications include 843 observations and the same other explanatory variables as in Table 4, but are not reported for brevity. Four model specifications are run separately and four different institutional measures take value 1, if the concerned measure is in place and 0 otherwise. Each measure is interacted with gap to the leader in (1), which measures the distance to the country-sector specific technology frontier, and with the catch-up dummy (2) taking 1 for those firms in each country with above the 80th percentile catch-up towards the frontier during the past year.

Table 8: Baseline results: Location-specific electricity market regulation

Dependent variable:	Institutional measure	Institutional measure
Solow residual	* Gap to leader	* Catch-up (D2)
	(1)	(2)
Lower total regulatory burden		
Main effect	0.065	0.057
	(0.024)***	(0.025)**
Interaction effect	-0.005	0.037
	(0.000)***	(0.005)***
Lower entry barriers		
Main effect	0.055	0.026
	(0.016)***	(0.017)
Interaction effect	-0.003	0.033
	(0.000)***	(0.004)***
Unbundling		
Main effect	0.015	-0.006
	(0.012)	(0.013)
Interaction effect	-0.004	0.044
	(0.000)***	(0.005)***
Privatization		
Main effect	0.081	0.068
	(0.026)***	(0.026)***
Interaction effect	-0.002	0.026
	(0.001)***	(0.005)***

Note: Standard errors are in brackets. ***,**,* indicate statistical significance at the 1, 5 and 10 percent levels, respectively. All specifications include 843 observations and the same other explanatory variables as in Table 4, but are not reported for brevity. Four model specifications are run separately and four different OECD indicators are considered to capture the openness of national market to competition. We invert the OECD indices bounded between 0 and 6, so that the highest values represent higher degrees of openness to competition. Each measure is interacted with gap to the leader in (1), which measures the distance to the country-sector specific technology frontier, and with the catch-up dummy (2) taking 1 for those firms in each country with above the 80th percentile catch-up towards the frontier during the past year.

Table 9: Robustness checks: Location-specific OECD measures of regulatory change

Dependent variable: TFP	Lower regulatory burden		Lower entry barriers		Unbundling		Privatization	
	Measure * Gap (1)	Measure * Catch-up (2)	Measure * Gap (5)	Measure * Catch-up (6)	Measure * Gap (3)	Measure * Catch-up (4)	Measure * Gap (7)	Measure * Catch-up (8)
Solow residual (SR)	-0.005	0.037	-0.003	0.033	-0.004	0.044	-0.002	0.026
	(0.000)***	(0.005)***	(0.000)***	(0.004)***	(0.000)***	(0.005)***	(0.001)***	(0.005)***
Robustness checks								
Olley-Pakes (OP)								
	-0.006	0.033	-0.004	0.027	-0.005	0.036	-0.003	0.028
	(0.001)***	(0.005)***	(0.000)***	(0.004)***	(0.000)***	(0.005)***	(0.001)***	(0.005)***
Ordinary Least Squares (OLS)								
	-0.004	0.029	-0.003	0.024	-0.004	0.034	-0.002	0.020
	(0.000)***	(0.005)***	(0.000)***	(0.004)***	(0.000)***	(0.004)***	(0.000)***	(0.005)***
Stochastic Frontier Estimation (SFE)								
	-0.005	0.033	-0.004	0.027	-0.005	0.038	-0.003	0.027
	(0.000)***	(0.005)***	(0.000)***	(0.004)***	(0.000)***	(0.005)***	(0.001)***	(0.005)***
Fixed Effects (FE)								
	-0.006	0.033	-0.005	0.027	-0.005	0.036	-0.003	0.029
	(0.001)***	(0.005)***	(0.000)***	(0.004)***	(0.000)***	(0.005)***	(0.001)***	(0.005)***
Generalized Method of Moments (GMM)								
	-0.004	0.028	-0.003	0.023	-0.004	0.032	-0.002	0.022
	(0.000)***	(0.004)***	(0.000)***	(0.004)***	(0.000)***	(0.004)***	(0.000)***	(0.005)***
Levinsohn-Petrin (LP)								
	-0.005	0.032	-0.004	0.026	-0.004	0.037	-0.003	0.022
	(0.000)***	(0.005)***	(0.000)***	(0.004)***	(0.000)***	(0.005)***	(0.000)***	(0.005)***

Note: Standard errors are in brackets. ***,**,* indicate statistical significance at the 1, 5 and 10 percent levels, respectively. All specfications include 843 observations and the same other explanatory variables as in Table 4, but are not reported for brevity. Four model specifications are run separately and four different OECD indicators are considered to capture the openness of national market to competition. We invert the OECD indices bounded between 0 and 6, so that the highest values represent higher degrees of openness to competition. Each measure is interacted with gap to the leader in (1), which measures the distance to the country-sector specific technology frontier, and with the catch-up dummy (2) taking 1 for those firms in each country with above the 80th percentile catch-up towards the frontier during the past year.

Table 10: Robustness checks: Sources of productivity improvements

	ln(material costs)it		ln(labor costs)it		ln(wage)it		ln(gross investments)it	
	FE	GMM	FE	GMM	FE	GMM	FE	GMM
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Liberalization effect	-0.024	-0.003	-0.006	-0.013	-0.004	0.001	0.012	0.006
	(0.029)	(0.015)	(0.009)	(0.008)	(0.014)	(0.011)	(0.013)	(0.009)
Catch-up dummy	-0.064	-0.069	-0.001	-0.027	0.014	-0.001	0.043	0.017
(D2)	(0.018)***	(0.161)***	(0.006)	(0.008)***	(0.043)	(0.010)	(0.017)**	(0.008)**
GDP	0.179	0.036	-0.039	-0.023	-0.058	-0.041)	-0.022	-0.012
	(0.053)***	(0.042)	(0.172)**	(0.021)	(0.023)**	(0.026)	(0.033)	(0.022)
Year effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	843	843	843	843	843	843	843	843

Note: Standard errors are in brackets. ***,**,* indicate statistical significance at the 1, 5 and 10 percent levels, respectively. Effect of liberalization is measured as years since implementation of the 2nd EC Liberalization Directive in 2003 and 0 otherwise. Dummy for catch-up firms takes value 1 for those firms in each country with above the 80th percentile catch-up towards the frontier during the past year.

the material inputs. Since no impact is found on wages in columns (5) and (6), it is possible that firms engaged in some downsizing to reduce the employment slack. Finally, it appears that investment intensity has gone up for high-productivity firms, suggesting that liberalization efforts could have induced some technology upgrading. Unfortunately, the firm-level data only allows the investigation of a limited number of channels through which productivity is improved, so I cannot directly track the firms' investment plans.

Also I cannot pin-down the potential price effects, since the panel data on electricity prices are not available for a sufficient time-span.[29] As previously discussed, Konings and Vandenbussche (2008) show that productivity improvements are largely due to policy measures and not due to a price effect.[30]

Previous literature shows that it is possible to estimate the effects of certain policy measures on productivity after one has shown that the same policy measures have affected the markups. One of the reasons is that the firm-level mark-ups reflect the competitiveness of the market, but cannot be treated as exogenous determinants of productivity developments. For example, very productive firms may gain market shares and extract the rents from less efficient firms.

A few papers show that the same reforms can influence on the one hand productivity and on the other hand the markups of firms. For example, Nickell (1996) and Nickell et al. (1997) show that regulatory reforms improved productivity of firms, while they increase competitiveness

[29] Eurostat has only recently begun to report systematically the time series of electricity prices charged to industrial and household consumers across European countries. The data I would need to examine the price-effect in a similar fashion as Konings and Vandenbussche (2008) do it for the manufacturing industry in their paper, are limited to the period after 2007 and therefore not suitable for the purpose.

[30] Mairesse and Jaumandreu (2005) directly evaluate the magnitude of price bias, since they have individual firm-level prices. They find that whether output is deflated with an industry-level price index, individual firm-level price index or not at all makes little difference for the estimated coefficients in the production function. This suggests that the ordinary practice of deflating output measures by 3-digit industry-level price indices when estimating production functions is an acceptable approach, as argued by Konings and Vandenbussche (2008). However, the literature is still debating on the magnitude of this potential price-bias. For example, Ornaghi (2006) and Katayama et al. (2005) suggest that the magnitude of price bias varies across different approaches used to estimate productivity.

reflected by lower markups of firms. Konings et al. (2005) find that antidumping protection raises the markups of different manufacturing firms and in their later paper, Konings and Vandenbussche (2008) show that the same antidumping measures have increased productivity of the same firms in the same period of time. While antidumping measures limit competition in the market, the liberalization measures are constructed so that higher values reflect greater openness of markets to competition.[31]

Moreover, taking into account the views on cost reduction and capital deepening discussed in the previous sub-sections, the results of Table 10 to a certain degree come close to the argument of Joskow (1997). The results suggest that the EC liberalization efforts have provided opportunities for modest reductions in operating costs of incumbents in the short run, particularly of material inputs.

Table 10 provides some evidence on raised gross investment in tangible fixed assets, but substantial savings from restructuring are likely to manifest in higher productivity only in the long-run, provided that regulation gives incentives for investments in new capacity. Since I observe little firm dynamics in the sample of firms, I interpret the above results as the firms' efforts to improve mid-term productivity particularly through reduction of material intensity and to a lesser degree by a better organization of labor, while larger shifts in the long-run are more likely to occur once the returns from capital investments are realized. And this holds merely for high-productivity firms close to the technology frontier.

5 Conclusion

This paper has presented a number of estimates of productivity and their relationship with the regulatory change following the efforts of European Commission to liberalize and harmonize the electricity market regulation across geographically localized markets. The results are consistent with the theoretical literature and imply modest improvements in productivity associated with deregulation and restructuring of the electricity industry. A considerable effort is made to explore various control measures to account also for regional dependence of firms and verify that these results are not sensitive to different measures of productivity.

The results suggest that productivity gains are only associated with the firms closer to the technology frontier, but very limited, if any, gains are observed for firms at lower orders of productivity. Productivity improvements are related to within-firm productive efficiency rather than reallocation of resources across firms. This is likely due to obstructed entry into the electricity industry, which largely depends on stringent regulation, congested infrastructure grid, market foreclosure and large capital investments needed for new establishments, as discussed for European electricity industry by Jamasb and Pollitt (2005) and Roeller et al. (2007). Joskow (1997) adds that while the most significant savings from restructuring are likely to be associated with efficient long-run investments in new capacity, there may be opportunities for modest productivity improvements of advanced electricity firms in the mid-term as found by the study. The results are rather intuitive, since productivity adjustments typically require longer time span, before investments in upgrading technologies are realized. Looking from the dynamic perspective, such transition is found to be slower for the lagging firms far from the technology frontier.

[31] As reckoned by Konings and Vandenbussche (2008) it is only when there is a positive correlation between the effects of same policy measures on the markups and productivity that one has to carefully look for additional control measures of price effects.

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6 Technical Annex A: Data

The data used in this study are the annual company accounts data reported at the end of each year, which are compiled from Amadeus organized by the Bureau van Dijk (van Dijk (2009)). I carefully compile the data on variables that proxy for institutional reforms from the national statistical offices and official reports of European Commission. The composite indicators of market regulation are retrieved from the OECD data originally compiled by Conway and Nicoletti (2006) and updated in 2009 (OECD (2009)). The additional annual data on control variables, i.e. the country-level real GDP growth rates, the real long-term interest rates, and the price index of investment goods, are obtained from the Ameco database from the ECFIN department at the European Commission. The product-level trade data are retrieved from Eurostat External Trade Database.

Regarding cleaning of the data, I exclude clearly wrong entries such as extremely high growth rates in employment, material or labor costs. I consider only those observations where the share of material costs and the share of labor costs in turnover is larger than 1 percent and smaller than 100 percent and exclude the extreme values of nominal growth in input and output. By doing so, I excluded roughly 2 percent of observations from the raw data. I consider only the firms that report active legal status to exclude the possibility that the results are affected by the firms in the consolidation process. Moreover, I consider only the firms from those countries for which I have comparable and complete information, that is, I are able to retrieve complete data for Austria, Belgium, Germany, France, Italy, Luxembourg, Norway, Portugal, Spain, and Sweden. After cleaning, the firm-level dataset reported in the summary statistics and used in the analysis is representative as it on average accounts for 95 percent (92 percent) of the aggregate Eurostat data in terms of employment (revenues) for the entire electricity sector.

The data cover a representative sample of firms in the electricity sector across a set of European countries for which complete and comparable data are available for the period 1996-2007. The firms are identified at the 4-digit Nace Rev.1.1 industrial activity level. The data allow us to distinguish each firm's participation in generation, transmission and distribution of electricity, classified under Nace Rev.1.1 codes 4011-4013. I obtain the indication of their diversification by referring to their reported status in primary and secondary codes of industrial classification. The sample of firms is the same as in the previous chapter of the thesis.

The variables used in the econometric models are the following. The firm-level operating revenue in each year provided in Amadeus is used to proxy the output variable. I prefer operating revenues to sales, because they include realizations of previous stocks, however the direction and significance of results do not change substantially when using sales instead of revenues. For the value of capital I use the book value of tangible fixed assets for each firm in each year. The labor costs reported in Amadeus proxy the wage bill variable. The material costs variable is simply proxied by the firm-level total material costs consisting of the factor price multiplied by the quantity of materials.

Several different variables at the national-sector and firm levels are constructed to proxy for institutional reforms in the econometric analysis. The EC Electricity Directives are defined in line with the EC official documents (Commission (2007a)). The measure of national legislation refers to the date of implementation of the first national Electricity Act.[32] The variable of operational regulatory authority refers to the date at which the country established an operating authority to regulate the national electricity market. The variable of wholesale market opening is based on the information on operation of organized market exchanges: Austria established EXAA in 2000, Belgium Belpex in 2006, Western Denmark joined in 1999 and Eastern Denmark in 2000 the Nord Pool, Finland joined the Nord Pool in 1998, France established Powernext in 2001, Italy Ipex in 2004, the Netherlands APX in 1999, Norway the Nord Pool in 1993, Portugal Mibel in 2004, Spain OMEL in 1998, Sweden joined the Nord Pool in 1996, England and Wales established the organized market in 1990 and since March 2001 formed NETA. The Greek and Luxembourgese wholesale electricity market were initiated in 2007. The Irish single electricity market (SEM) was agreed in 2004, but trading began in 2007. The measure of full and initial retail market opening are based on the information about national retail electricity markets for industrial users and respectively for household users. At these dates, consumers are given a choice to choose between different electricity suppliers. In the first years of initial opening for most European countries during 1998-2001, the share of consumer switching across the countries varied from low 2% (Belgium) and medium 10-

[32] See the legislative texts by Commission (2003a), Commission (2003b),Commission (2004).

30% (Austria, France, Germany, Ireland, Luxembourg, the Netherlands, Spain, Portugal) to over 50% (the Nord Pool and the UK) for the large industrial consumers. In a comparable period, switching of small industrial consumers and households remained below 10% for most countries, except the Nord Pool and the UK (30-50%). All these variables take 0 in the pre-event window and the number of years since its implementation in each consecutive year of the post-event window to capture the gradual effect of reform steps.

The measures on liberalization efforts above are complemented by the OECD database on indicators of regulation in energy, transport and communications (ETCR, OECD (2009)). "Index of regulatory constraints", "Index of entry barriers", "Index of vertical integration", and "Index of state ownership" refer to the composite indices originally compiled by Conway and Nicoletti (2006). The indices are bounded by the interval [0,6], where higher values represent larger constraints of market regulation. "Index of regulatory constraints" combines information in three main areas, i.e. state control, barriers to entry, and involvement in business operations. All of these regulatory data are vetted by Member country officials and/or OECD experts. The indicators are calculated using a bottom-up approach in which the regulatory data are quantified using an appropriate scoring algorithm. Further detailed information on construction and robustness of these indicators are reported by Conway and Nicoletti (2006). For the purpose of the study I invert the values of OECD indices, so that the highest values represent greater competition.

The sources are the following. The information about national legislation, wholesale and retail markets is compiled from the official documents of national regulatory authorities, i.e. Electricity Regulatory Authority (E-Control) for Austria, Commission for Electricity and Gas Regulation (CREG) for Belgium, Energy Regulatory Authority (DERA) for Denmark, Energy Market Authority (EMV) for Finland, Electricity Regulation Commission (CRE) for France, Federal Network Agency for Electricity, Gas, Telecommunications, Posts and Railway (BnetzA) for Germany, Regulatory Authority for Energy (RAE) for Greece, Commission for Energy Regulation (CER) for Ireland, Regulatory Authority for Electricity and Gas (AEEG) for Italy, Luxembourg Institute for Regulation (ILR) for Luxembourg, Office of Energy Regulation (DTE) for the Netherlands, Norwegian Water Resources and Energy Directorate (NVE) for Norway, Energy Services Regulatory Authority (ERSE) for Portugal, National Energy Commission (CNE) for Spain, Swedish Energy Market Inspectorate for Sweden, Office of Gas and Electricity Markets (Ofgem) for the UK. Computations based on indicators of electricity retail market competition by Al-Sunaidy and Green (2006). The composite indices are retrieved from the OECD market regulation database, which is compiled by Conway and Nicoletti (2006).

7 Technical Annex B: The Olley-Pakes Method

Olley and Pakes (1996) model builds upon a structural model that allows identification of productivity by using the notion that under imperfect competition growth in inputs leads to disproportional growth in output. As noted previously, a key issue that emerges in the estimation of production functions is the possible simultaneity problem between input choice and productivity yielding inconsistent estimates. Unlike Hall (1988), Olley and Pakes (1996) method does not require any instruments to control for unobserved productivity.

Based on a behavioral framework, the Olley and Pakes (1996) method solves the simultaneity problem by using the firm-level investment decision to proxy for unobserved productivity shocks and controls for the endogenous firm exit from the sample by incorporating a decision rule into a dynamic model of firm behavior. The model assumes the following Cobb-Douglas production function with all variables in small letters expressed in logarithms as:

$$q_{it} = \beta_0 + \beta_l l_{it} + \beta_m m_{it} + \beta_k k_{it} + e_{it} \tag{B.1}$$

$$\text{where } e_{it} = \omega_{it} + \eta_{it}$$

where the output of firm i at time t, y_{it}, is a function of labor, l_{it}, materials, m_{it}, and capital, k_{it}. The firm-specific error term, e_{it}, has two components, a white noise component, η_{it}, and a time varying productivity shock, ω_{it}, which is known to the firm but unobservable to the econometrician. This productivity shock, ω_{it}, is a state variable that can impact the firm's choice of variable labor,

l_{it}, and materials, m_{it}, leading to simultaneity problems. Moreover, capital is a state variable, only affected by the current and past values of unobserved productivity, ω_{it}. Investment is calculated as a function of capital with depreciation rate δ_{it} and it is specified as:

$$I_{it} = K_{it+1} - (1 - \delta_{it})K_{it}$$

Hence, the firm investment decisions depend on capital and productivity, formulated as $I_{it} = i_t(k_{it}, \omega_{it})$. A crucial assumption of the Olley and Pakes (1996) method is that the firm-level investments are positive, $I_{it} > 0$, so that the investment decision can be inverted to express unobserved productivity as a function of the observable capital and investment that are used to proxy for ω_{it} in (B.1) with $g_t = i_t^{-1}(k_{it}, \omega_{it})$:

$$\omega_{it} = g_t(k_{it}, I_{it}) \tag{B.2}$$

Consider (B.2) and differentiate a time varying productivity shock, ω_{it}, as:

$$\Delta\omega_{it} = g_t(k_{it}, I_{it}) - g_t(k_{it-1}, I_{it-1}) \tag{B.3}$$

Equation (B.3) expresses the unobservable change of productivity shock as a function of observable capital and investment. Olley and Pakes (1996) suggest an algorithm to proxy for this function by a polynomial in capital and investment, $\phi_{it}(k_{it-n}, ..., k_{it}, I_{it-n}, ..., I_{it})$ *with* $n = 1, .., N$, in order to control for the unobserved productivity when estimating the price-cost margin. Practically, the length of polynomial depends on the time span of the data and typically it is sufficient to use the fourth-order polynomial, that is $n = 1, .., 4$. To control for potential selection bias, Olley and Pakes (1996) use information on firm dynamics in the first step of the estimation procedure. Productivity is assumed to follow a a first order Markov process, i.e. $\omega_{it+1} = E(\omega_{it+1}|\omega_{it}) + \xi_{it+1}$, where ξ_{it+1} represents the news component, which is assumed to be uncorrelated with the variable inputs, labor and materials. Firms will continue to operate provided their survival if their productivity is above a lower bound: $\omega_{it} \geq \omega_{it}^*$. The survival indicator $\chi_{it+1} = 1$ if $\omega_{it} \geq \omega_{it}^*$denotes

the firm's i survival. The second step of the estimation procedure considers the expectation of $y_{it+1} - \beta_l l_{it+1} - \beta_m m_{it+1}$, conditional on the survival of the firm i:

$$E\left[y_{it+1} - \beta_l l_{it+1} - \beta_m m_{it+1} | k_{it+1}, \chi_{it+1} = 1\right] = \beta_0 + \beta_k k_{it+1} + E\left[\omega_{it+1} | \omega_{it}, \chi_{it+1} = 1\right]$$

and is derived as follows:

$$y_{it+1} - \beta_l l_{it+1} - \beta_m m_{it+1} = \beta_0 + \beta_k k_{it+1} + h(P_{it,}\phi - \beta_k k_{it}) + \xi_{it+1} + \eta_{it} \tag{B.4}$$

where $h(P_{it,}\phi - \beta_k k_{it}) = E\left[\omega_{it+1}|\omega_{it}, \chi_{it+1}\right]$ according to the law of motion of the productivity shocks. P_{it} is the probability of survival of firm i in the next period, i.e. $P_{it} = \Pr\left(\chi_{it+1} = 1\right)$. A consistent estimate of the capital coefficient is obtained by substituting the estimated coefficients on labor and materials from the first stage and the estimated probability of survival in Eq. (B.4). As in the first stage of the procedure the function $\phi_{it}(k_{it-n}, ..., k_{it}, I_{it-n}, ..., I_{it})$ is approximated by a forth order polynomial expansion. Estimating the above Eq. (B.4) by applying non-linear least squares I obtain a consistent estimate of the capital coefficient. Finally, using the estimates of the input coefficients obtained with the Olley and Pakes methodology, I compute the log of firm's i TFP at time t as:

$$tfp_{it} = y_{it} - \widehat{\beta}_0 + \widehat{\beta}_l l_{it} + \widehat{\beta}_k k_{it} + \widehat{\beta}_m m_{it} \tag{B.5}$$