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From Liberalization Towards Integration: Have Markups of EU Electricity Firms Changed?

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From Liberalization towards Integration: Have Markups of EU Electricity Firms Changed?

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May, 2010

Abstract

This paper presents an ex-post empirical analysis of the impact of European electricity market reforms on markups of firms. The working hypothesis is that further economic integration would bring competition into electricity markets reflected by lower markups of electricity firms. The results show that reforms have gradually reduced the markups, but the markup premium of incumbent firms is on average larger than theoretical models would predict under effective economic integration. Considering regional proximity and heterogeneity of firms along the supply chain, the results suggest that better market access and cross-border arbitrage disciplined the markups, but have not led to competitive market outcomes due to prevailing market concentration and insufficient unbundling of transmission and distribution channels.

JEL no. F10, L11, L51, L94

Keywords: Economic integration; electricity firms; EU; price-cost margins; service market regulation

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1 Introduction

European electricity market reforms in the last decade were meant not only to secure reliable and safe supply of electricity but also to bring more competition in the market (Commission (2007a) and Commission (2007b)). Liberalization of European electricity sector would ideally integrate national systems into a single European electricity market and therewith mitigate the markups of incumbent electricity firms (e.g. Smeers (1997), Smeers (2005)). This paper investigates to what extent EU regulatory measures induced competition as reflected by the markups of electricity firms. Providing systematic evidence on responsiveness of firms' markups towards regulatory measures is relevant for an accurate assessment of their effectiveness, nonetheless because markups in the upstream sector can be passed on consumers in downstream sectors through higher prices (see Arnold et al. (2006) and Arnold and Scarpetta (2008)). Previous literature guides the economic mechanism in support of the econometric analysis (in particular, Laffont and Tirole (1993), Wolak (1994), Borenstein et al. (2002)). In the neoclassical profit-maximization models firms charge high prices to obtain high markups, but economic integration facilitates pro-competitive effects reflected by lower markups. In a similar vein, the agency asymmetric pricing models suggest that re-regulation provides incentives for markup adjustments to the level of competitive rivals. A simple theoretical model presented in this paper follows Bushnell et al. (2008) to demonstrate that restructuring towards greater integration leads to more competitive outcomes. A decline in the average markup is linked to increased competition from restructured electricity systems, which facilitates trading activity to arbitrage electricity between different national markets.

The econometric model builds upon the Roeger (1995) approach, which main advantage is that it does not suffer from endogeneity issues when estimating firm-specific markups. The measures of regulatory changes are constructed carefully to consider complementarity and sequencing of reforms, as motivated by Dewatripont and Roland (1992) and Dewatripont and Roland (1995). The empirical analysis confirms the theoretical predictions showing that reforms have gradually reduced the markups. A decomposition of the markup change indicates that better market access and cross-border arbitrage lead to lower markups, while greater market concentration and bundling of transmission and distribution channels have the opposite effect. Moreover, private-owned firms appear to have lower markups in concentrated markets where barriers of entry are high. The results are consistent with the studies by Wolfram (1999), Jamasb and Pollitt (2005) and Roeller et al. (2007), which argue that imperfectly competitive outcomes are largely due to insufficient unbundling, rigid financial contracts and limited cross-border arbitrage of electricity constrained by poor investments into the interconnection grid. The results are robust to alternative specifications and controlled for the firm-specific attributes inherent to the electricity sector.

Conceptually, the price-cost margin measures the extent to which firms are able to exercise their market power. The marginal cost is typically not directly observed by analysts, since costs are the private information of firms. As it has been commonly applied in the electricity market studies, the presumed marginal cost in the measures of price-cost margins is the average cost or operating cost of the last generator that would be dispatched to meet energy demand (Joskow (1997) and Brennan (2004)). As pointed out by Brennan (2004), even the most expensive marginal generator has to expect that prices will on average not only cover variable costs but also fixed capital costs. Therefore, high markups do not necessarily mean that firm has large market power at all times, but rather that market power is exercised in times of capacity constraints. This might particularly be problematic, if one estimates price-cost margins based on high-frequency data with daily peak

and off-peak levels of demand. High short-term price-cost margins might then not indicate anti-competitive pricing of firms, but rather that firms are approaching their capacity limits (Brennan (2004)). To assess if these prices are inappropriately high relative to marginal costs one would ideally like to compare discounted present value of revenues received from electricity sales of a firm rather than individual plant over longer time span.

This paper takes into account these concerns. First, I consider that market liberalization may not yield significantly different impact for firms within the group of the parent company and instead treat these plants in a consolidated way, i.e. aggregated up to the firm level. Second, I consider regional proximity of firms and potential capacity constraints related to the size of interconnected infrastructure grid by clustering those firms which are in close competition within the markets defined. Third, I consider annual data rather than high-frequency data to avoid estimating markups at peak levels of demand. Fourth, I identify different types of firms (i.e. generating, transmitting and distributing firms) and include a dummy variable distinguishing them in econometric estimations. Finally in the sensitivity analysis, I consider not only fixed capital but also variable capital of firms.¹

The remainder of the paper is structured as follows. Section 2 describes in more detail European regulation of the electricity systems. Section 3 presents a theoretical framework that guides the empirical analysis. Section 4 develops the empirical strategy to estimate the price-cost margins of firms and their casual relationship with the regulatory changes. Section 5 presents the main results and discusses the robustness checks. Section 6 concludes.

2 Institutional Background

Liberalization initiatives in Europe have begun in the beginning of 1990s following the launch of the Single European Act.² 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 price-cost margins and costs of electricity firms resulting from fiercer competition.

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 and Pollitt (2005)).

2.1 EU Electricity Market Directives

Distinct characteristics of the electricity sector have shaped Commission's liberalization efforts. Different optimal economies of scale characterize four main segments in the electricity industry, which are generation, high-voltage transmission, low-voltage distribution and retailing of electricity to consumers (Green (2006)). Initially, an electricity firm has a large investment cost in infras-

¹The revenues and costs of firms are considered in real terms using appropriate country-sector specific deflators.

²See the official texts by Commission (2003a), Commission (2003b), Commission (2004)).

structure that does not depend on output, but the marginal cost of transmitting and distributing additional units of electricity is roughly constant and small. An electricity firm has thus large incentives to bundle electricity generation with transmission, distribution and retailing to electricity consumers. Since electricity is non-storable, a certain degree of regulation is nonetheless needed to secure its delivery through an infrastructure grid with balanced supply and demand at all nodes (Jamansb and Pollitt (2005)).

Up to date, there have been three step-wise EU Electricity Market Directives. The first directive was implemented in 1996 and enforced by 1997 to promote competition based on three pillars: First, by opening competition in electricity generation process, second, to facilitate access to infrastructure grid, and third, to initiate unbundling of services provided by vertically-integrated electricity firms. While stipulating a certain degree of progress at national level, the first directive left discretion to Member States with regard to introducing competition by implementing each of these reform steps (Commission (2003a), Commission (2003b), Commission (2004)).

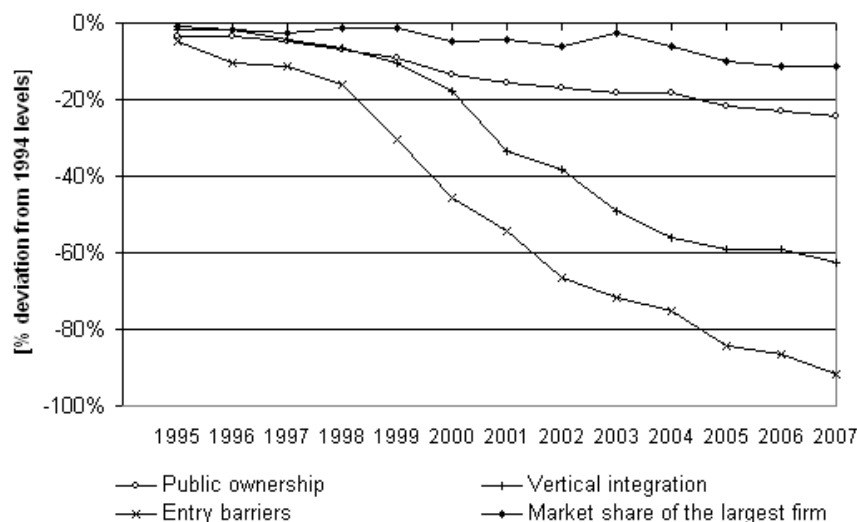
The progress under the first directive was limited and there was need for the second directive to set stricter objectives. The second EU Electricity Market Reform was launched in 2003 and aimed at freeing the entry into electricity generation, unbundling of transmission and distribution channels, monitoring competition in retail and wholesale supply by independent national authority, strengthening the role of regulator to secure safe and reliable supply, and ultimately establish a single European market for electricity (Commission (2003a), Commission (2003b), Commission (2004)). In September 2007, the EU Commission proposed the third electricity market directive with amendments of the previous directive. The main changes were that all Member States should have established independent regulators of the electricity and gas markets and that generation, transmission, and distribution should have been further separated than before (Commission (2003a), Commission (2003b)). To investigate how differences in liberalization efforts across different EU countries influenced the markups, I construct several proxy variables of electricity market reforms. 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 proxy a *de jure* national policy by the number of years passed since the implementation of the first national Electricity Act. Similarly, I proxy a *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.

2.2 Introducing Competition in the Market

The EU Electricity Market Directives recognized that liberalization requires a suitable market structure within which effective competition can be achieved. On the one hand, the reform steps aimed at separating generation from transmission and distribution channels. On the other hand, the reform steps aimed at horizontal splitting of market concentration of the largest firms to create effective competition in generation and retailing where economies of scale favor competition (Jamansb (2002), (Joskow (2003) and (Newberry (2002))).

The electricity is a rather homogeneous product for which high fixed costs deter entry of potential competitors. If a firm controls the entire supply chain, the situation easily resembles natural

Figure 1: Indicators of market opening to competition



monopoly where the largest supplier has an overwhelming cost advantage over potential competitors in the market. An electricity firm faces large start-up costs independently of output, while marginal cost of transmitting and distributing additional units of electricity are much lower and stable over time. The market for electricity is regionally fragmented with rather inelastic demand elasticity as electricity consumption relies on a potentially congested transmission network (e.g. Joskow (1997), Joskow (2003), Jamasb and Pollitt (2005), Wolak (2006) and Roeller et al. (2007)). Hence, the size of electricity firms is not unambiguously linked to the level of markups, since the firms with very small market shares can exert substantial markups in periods of high demand when generation capacity is tight and their output is required to satisfy demand (Borenstein et al. (2002), Smeers (2005), Bushnell et al. (2008)).

There is a large regional fragmentation with several electricity systems in the EU roughly divided according to the interconnected grid into the UK-Ireland zone, Nordic zone including Norway, west European zone, Iberian zone and Italian zone (ERGEG (2008), Roeller et al. (2007)). Figure 1 presents evolution of different indicators of reform steps across these zonal markets. The plotted lines refer to the average values of each indicator across EU15 and Norway.

The indicators of entry barriers, vertical integration and public ownership are calculated by using the OECD database on market regulation in energy, transport and communications (OECD (2009)). The indicator of entry barriers is based upon information on the terms and conditions of third party access (TPA) to the electricity transmission grid, the liberalization degree of wholesale markets, and the minimum consumption thresholds that consumers must exceed so they can choose freely their electricity supplier. The index of vertical integration builds upon information on the degree of vertical separation between the transmission and generation segments of the electricity industry. The market share of the largest electricity firm is based on the Eurostat electricity industry data. As shown by Figure 1, national markets have become increasingly open to competition, but with far less unbundling of vertical channels and weak progress in horizontal splitting of firms' market shares. The preliminary evidence presented by Figure 1 and Table A1 show there is a considerable variation across European countries in terms of specific regulatory areas.³ This evidence

³Roeller et al. (2007), ERGEG (2007) and ERGEG (2008)) also document large variation in degrees of internal

motivates the econometric analysis, where I expect that price-cost margins will be positively associated with market concentration, but could have gradually declined over time due to increased competition fostered by liberalization efforts.

2.3 Ownership

Joskow (1997) argues that production of electricity used to rely intensively on public or private monopoly suppliers, whose strategic behavior has been regulated by governments. On the one hand, the cost-inefficient storage of electricity, the limited interconnection capacities and availability of technology have favored large and vertically integrated generation facilities owned by a small number of firms. On the other hand, the institutional barriers have hampered competitive gains that could emerge from unbundled products among which consumers could switch easily.⁴

Figure 1 plots the index of public ownership retrieved from the ETCR database (OECD (2009)), which builds upon information of the ownership structure of the largest companies in the generation, transmission, distribution, and supply segments of the electricity industry. State involvement in electricity sector has reduced by about 24% over 1994-2007, but there has been little reduction in horizontal market concentration on average about 11% across Europe (from 58% to 52% over 1994-2007). This suggests that firms might have reacted to liberalization efforts. If firms could not have influenced the market rules, they could have influenced the market structure by increasing their cross-border market shares through changes in ownership structure (Green (2006)).

Damijan et al. (2005), Damijan and Knell (2005) and Konings et al. (2005) suggest that privatization could lead to more competitive outcomes as the changes in ownership structure improve the performance of firms, however conditional on the prevailing market concentration. There is evidence that privatization delivers benefits when combined with effective restructuring and regulation (Newberry and Pollitt (1997) and Newberry (2002)).⁵ An increase in sector-wide ownership diversity can facilitate direct competition in the generation and supply activities and yardstick regulation of networks by comparative performance (Jamansb and Pollitt (2005)). Privatization can also provide significant proceeds for the government and reduce its future liabilities (Newberry and Pollitt (1997)). However, privatization is not a prerequisite for liberalization. In theory, competition and incentive regulation can be applied to publicly owned firms (e.g. Norway as discussed by Jamansb and Pollitt (2005)).

3 Theoretical Framework

The recent theoretical literature assessing the market power of electricity firms typically refers to structural equilibrium models, which are discussed in more detail by Smeers (2005). In principle, an equilibrium unit commitment model decomposes a period of time into smaller segments at which

competition and note that the Nordic market is the most advanced in terms of effective international integration, while the Iberian and Italian markets are particularly lagging behind. The authors emphasize the importance of west European market, which is the largest regional market and its development determines further progress toward an integrated European electricity market.

⁴The environment has been evolving and development of new technologies does not exclusively favor large generation utilities in order to gain from economies of scale and scope. Moreover, electricity is becoming increasingly differentiated product in terms of ecological compliances, reliability and safety of supply (Commission (2007a), Commission (2007b), Roeller et al. (2007)).

⁵The issues of privatization and legal separation of transmission and distribution from generation are often inter-related. As noted by Green (2006), to ensure efficient and non-discriminatory network access, it is appropriate that distribution and transmission systems are operated through legally separate entities where vertically integrated undertakings exist (Green (2006)).

the output and market price are assumed to be fixed (Smeers (2005)).⁶ Consumers $h \in \{1, \dots, H\}$ have inverted demand function $p_t(d_{ht})$ at each period of time and firms $i \in \{1, \dots, N\}$ maximize their profits by choosing the operation level of each running unit to satisfy the demand of consumers at minimal cost $C_{it}(q_{it}) = K_{it} + c_{it}q_{it}$, which may include both start-up capacity costs (K_{it}) and operational variable costs ($c_{it}q_{it}$). In the equilibrium model, demand and supply instantaneously meet at every period of time t , so that $\sum_{i=1}^N q_{it} = \sum_{h=1}^H d_{ht}$.

The unit commitment model has been among others used by Joskow and Kahn (2002) and Borenstein et al. (2002), in which marginal costs of electricity generation are simulated for different periods of time and compared to the observed prices in these periods. Bushnell et al. (2008) additionally apply a counterfactual approach to compare the perfectly competitive outcomes with the outcomes of Cournot type of competition. In this model, firms exercise market power, if the simulated price under Cournot competition exceeds the perfectly competitive price.⁷

The framework presented below follows closely Bushnell et al. (2008) to provide economic intuition about the link between integration and the markups of firms. The model demonstrates that economic integration in terms of greater integration of wholesale and retail markets imposes downward pressure on the markups of incumbent firms that are simultaneously exposed to external competition, for example, from the electricity supplied through the cross-border imports or by smaller units operating only at certain periods of time (see Borenstein et al. (2002)). The model by Bushnell et al. (2008) is an elegant version of the equilibrium unit commitment model, which considers Cournot competition at the wholesale and retail levels. Firms thus maximize profits by using production quantities as the strategic decision variable. The total production of firm i at time t is represented by q_{it} and the retail sales are denoted by q_{it}^r . Following Bushnell et al. (2008), each strategic firm i at independent period of time t maximizes its profits:

$$\pi_{it}(q_{it}, q_{it}^r) = p_t(q_{it}, q_{(N-1)t})[q_{it} - q_{it}^r] + p_t^r(q_{it}^r, q_{(N-1)t}^r)q_{it}^r - c_{it}q_{it} - K_{it} \quad (2.1)$$

where $q_{(N-i)t}$ and $q_{(N-i)t}^r$ are the quantity produced and retail quantity supplied by the other $(N-i)$ firms in Eq. (2.1) and p_t and p_t^r are the wholesale and retail market prices, respectively. In general, the equilibrium positions of firms consider both wholesale and retail demand elasticities as well as production capacity (K_{it}) and marginal costs (c_{it}). However, in the unit commitment model both retail quantity and prices are fixed at each unit or segment of time t . Under these assumptions, Bushnell et al. (2008) develop the Cournot equilibrium as the set of quantities that simultaneously satisfy the first order conditions for each firm i at time t as:

$$\frac{\partial \pi_{it}}{\partial q_{it}} = [p_t(q_{it}, q_{(N-i)t}) - c_{it}(q_{it}) - r_{it}(q_{it})] \geq [q_{it}^r - q_{it}] \frac{\partial p_t}{\partial q_{it}} \quad (2.2)$$

Equation (2.2) shows that the retail position of firm i matters for the level of its markup. As the retail supply increases towards the quantity produced, the marginal revenue approaches the wholesale price. This implies that the Cournot model with greater economic integration of wholesale and retail markets leads to the markups, which are closer to a competitive outcome, where the market price equals marginal revenues of the firm (see Bushnell et al. (2008)). The

⁶The backbone of the equilibrium unit commitment models is the optimal dispatch model, which has been developed by the electrical engineers to solve short-run optimizations of the generation systems to satisfy an exogenously given demand, as discussed in more detail by Smeers (2005).

⁷This framework has been further extended to include other attributes of the electricity sector, such as electricity transmission and price discrimination between different types of consumers as discussed by Smeers (2005).

difficulty of these models arises from identification of the marginal cost curve in the market. Within a certain period, different units of firms may operate at different segments of marginal cost curve, depending on the overall utilization of capacity in the market.⁸ In general, the marginal costs of firm i can be defined as:

$$p_t(q_{it}, q_{(N-i)t}) - c_{it}(q_{it}) - r_{it}(q_{it}) \geq 0 \quad (2.3)$$

where the pure markup premium ($p_t - c_{it}$) should exclude the rent of capacity utilization $r_{it}(q_{it})$ to assure the investment incentives of firms in terms of scarcity rents of capacity K_{it} , as pointed out by Smeers (2005).⁹ The wholesale market price is determined from the firms' residual demand function (Q_{it}), which equals the market demand (Q_t^m) net of supply from imports $\sum_{j=1}^M q_{jt}(p_t)$ and the fraction $\sum_{f=1}^F q_{ft}(p_t)$ of small units $f \in \{1, \dots, F\}$ that supply electricity only at the peak levels of demand. Bushnell et al. (2008) model the additional supply as a function of price, thereby providing price responsiveness to Q_{it} as:

$$Q_{it}(p_t) = Q_t^m - \sum_{j=1}^M q_{jt}(p_t) - \sum_{f=1}^F q_{ft}(p_t) \quad (2.4)$$

The simple model above demonstrates that restructuring towards greater integration leads to more competitive outcomes. Moreover, a decline in the average markup is linked to increased competition from restructured electricity systems, which facilitates trading activity to arbitrage between different markets.

In what follows, I look for a testable econometric model to estimate the response of electricity firms' markups to reforms aimed at integrated European electricity market. The marginal costs are very difficult to measure directly in the data as pointed out in the previous literature. Smeers (2005) notes that the relevant cost is the long-run marginal cost, which is equal to the short-run marginal cost only when the electricity system is optimally dimensioned and prices are sufficient to justify new investments. By contrast, comparing prices with short-run variable costs may lead to upward biased estimates of markups, reflecting the short-run excessive market power in situations of tight capacities. Borenstein et al. (2008) use unique US data, which allows them to explicitly model marginal cost curve for a certain fraction of electricity units, but for the rest of them they find it impractical due to data limitations. These concerns are considered in the following subsections to formulate testable econometric model that allows a direct estimation of the average long-term markup for a representative sample of European electricity firms.

⁸For example, the hydro-plants may operate exclusively at the peak-loads in certain periods of time, when demand for electricity exceeds the capacity of other sources of electricity, while the nuclear plant must operate permanently due to technical requirements. The short-term demand is rather inelastic and companies with very small market shares can sometimes exert substantial market power in periods of high demand when generation capacity is tight and their output is required to satisfy demand (Borenstein et al. (2002), Smeers (2005)).

⁹Smeers (2005) discusses different extensions of equilibrium models to account for the investment decision function of firms to invest in their capacities. Firms invest in new capacities, if they can sell their output forward over the long run. In principle, this model under certain assumptions comes close to Bushnell et al. (2008) in predicting that a forward commitment towards the greater amount produced leads to more competitive outcomes as the marginal revenue approaches the wholesale price.

4 Empirical Methodology

4.1 Baseline Model

The fundamental measure of the exercise of market power is the price-cost margin, which measures the degree to which prices exceed marginal costs. Prices above marginal cost lead to inefficient allocations, because of relatively low consumption at uncompetitive prices. In most industries, it is not possible to directly calculate price-cost margins, because marginal costs are usually privately-held information of firms (Borenstein et al. (1999)). Hence, the Roeger (1995) approach is used to specify the baseline econometric model. The main intuition of this method is that the markup term is embodied in the measurement of the total factor productivity (TFP) growth, which is the output growth not accounted for by the growth in inputs. Roeger (1995) exploits the earlier empirical findings (e.g. Abbot et al. (1989)) that productivity measure can be estimated either as the residual in the production function or as the residual of the dual cost function. In fact, Roeger (1995) argues that the dual Solow residual capturing output and production factor prices nests the same productivity term that will cancel out, if the dual Solow residual is deducted from the primal Solow residual (Solow (1957)).¹⁰ I hereby outline the baseline model, while the necessary derivation steps are explained in Appendix.

Consider a log-linear production function $Q_{it} = G(K_{it}, L_{it}, M_{it})E_{it}$ for output Q_{it} , where K_{it} , L_{it} , and M_{it} are capital, labor and material inputs (I_{it}) and E_{it} is a shift variable representing changes in productivity efficiency of a firm i at time t . That is, total factor productivity (TFP) is a residual between actual and potential output and this consideration is standard in literature (e.g. Hall (1988), Harrison (1994), Olley and Pakes (1996), Fabrizio et al. (2007)). Roeger (1995) circumvents the potential problem coming from the correlation of inputs with the output by subtracting the price-based from the output-based Solow residual. Decomposition of the markup and the technology component from the output-based Solow residual SR_{it} and price-based Solow residual SRP_{it} is a crucial step in the Roeger method and are expressed as:

$$SR_{it} = \mu_{it}(\Delta q_{it} - \Delta k_{it}) + (\xi_{it} - \mu_{it})e_{it} \quad (2.5)$$

$$SRP_{it} = \mu_{it}(\Delta F_{Kit} - \Delta p_{it}) + (\xi_{it} - \mu_{it})e_{it} \quad (2.6)$$

where the right-hand side is decomposed in the markup and the pure technology component, where Lerner index for a firm i at time t is denoted by $\mu_{it} = \frac{P_{it} - c_{it}}{P_{it}}$, scale economies are denoted by ξ_{it} and small letters refer to the logarithms.¹¹ Similar to Fabrizio et al. (2007), I hereby implicitly assume that production factors are to a certain degree substitutable only in the long-run, but fixed in the medium-run.¹²

The output-based and price-based residuals are respectively the differences between the growth rates of output Δq_{it} and weighed inputs $\alpha_{Iit}\Delta I_{it}$, and alternatively the differences between the growth rates of output prices Δp_{it} and weighed input prices $\alpha_{Iit}\Delta F_{Iit}$. More formally, the Solow residuals can be expressed as:

¹⁰Such approach for deriving of the markups under imperfect competition has been further followed by, among others, Martins et al. (1996), Konings and Vandebussche (2005), and Vandebussche and Zarnic (2008).

¹¹Roeger (1995) shows that the change in the marginal cost (Δc_{it}) is a weighted average of the changes in input prices (F_{Iit}) with respect to their relative cost shares in the firm's cost function (ϕ_{Iit}), accounting for the change in technology (e_{it}), i.e. $\Delta c_{it} = \phi_{Iit}\Delta F_{Iit} - \Delta e_{it}$. The original Roeger (1995) method is adjusted to variable returns to scale by weighting the production function by economies of scale ξ_{it} , estimated by the least squares (LS).

¹²This assumption is relaxed in the next sub-section, in which I consider that firms can adjust a fraction of their capital to current demand shocks.

$$SR_{it} = \Delta q_{it} - \sum_I \alpha_{Iit} \Delta I_{it} \quad (2.7)$$

$$SRP_{it} = \sum_I \alpha_{Iit} \Delta F_{Iit} - \Delta p_{it} \quad (2.8)$$

where the share of inputs (I_{it}) in total revenues ($P_{it}Q_{it}$) are denoted by $\alpha_{Iit} = \frac{F_{Iit}I_{it}}{P_{it}Q_{it}}$ with the letters F and P representing input and output prices. To obtain a price-cost margin term $\mu_{it} = \frac{P_{it}-c_{it}}{p_{it}}$, which can be directly estimated, one has to subtract the price-based residual SRP_{it} from the output-based residual SR_{it} as:

$$(\Delta q_{it} + \Delta p_{it}) - \sum_I \alpha_{Iit} \Delta F_{Iit} = \mu_{it} [(\Delta q_{it} + \Delta p_{it}) - (\Delta k_{it} + \Delta F_{Kit})] \quad (2.9)$$

The price-cost margin term (μ_{it}) in (2.9) can be estimated consistently, because the error term capturing unobserved productivity shocks has canceled out. The baseline econometric model is thus simply specified as:

$$\Delta y_{it} = a_i + \mu_1 \Delta x_{it} + \varepsilon_{it} \quad (2.10)$$

where the left-hand side variable (ΔY_{it}) represents the difference between the Solow residuals and the right-hand side explanatory variable (ΔX_{it}) represents the growth rate of output per value of capital with the white noise error term ε_{it} for firm i at time t . In the empirical analysis, I first compute the average returns of scale ξ_{it} at the 3-digit electricity industry level from the production function $Q_{it} = E_{it} K_{it}^{\alpha_K} L_{it}^{\alpha_L} M_{it}^{\alpha_M}$ to compute the weighted shares of input costs ($\sum_I \alpha_{Iit} \Delta F_{Iit}$) in Eq. (2.9) as:¹³

$$\sum_I \alpha_{Iit} \Delta F_{Iit} = (\xi_{it} - \alpha_{Lit} - \alpha_{Mit}) \Delta F_{Kit} + \alpha_{Lit} \Delta F_{Lit} + \alpha_{Mit} \Delta F_{Mit}$$

4.2 Alternative Approach: Variable Capital Model

In this approach, firms can adjust a fraction of their capital assets to current demand shocks as previously formulated by Roeger and Warzynski (2004). This extension allows us to come closer to the estimate of pure markup premium, which is controlled for the part of scarcity rent of capacity utilization r_{it} in (2.2) providing incentives for future investments. In other words, capital consists of a fixed component and a variable component. This approach allows the sunk costs, which characterize the electricity sector, to be taken explicitly into account by considering a component of variable capital in the estimation of markups.

Consider a log-linear production function $Q_{it}^s = \min(\alpha_{Lit} L_{it}, \alpha_{Kit} K_{it}^v) - K_{it}^f$ with the variable capital input $K_{it}^v = s_{it} K_{it}$ where s_{it} measures the degree of variable capital within the capital stock K_{it} .¹⁴ Similar to Roeger (1995) with the share of inputs in revenues, consider now the share of inputs in total costs. The output and price-based Solow residuals are defined as:

$$SR_{it}^s = \Delta q_{it} - (\alpha_{Kit}^s \Delta k_{it} + \alpha_{Lit}^s \Delta l_{it} + \alpha_{Mit}^s \Delta m_{it}) + \Delta e_{it} \quad (2.11)$$

$$SRP_{it}^s = \alpha_{Kit}^s \Delta F_{Kit} + \alpha_{Lit}^s \Delta F_{Lit} + \alpha_{Mit}^s \Delta F_{Mit} - \Delta p_{it} - \Delta e_{it} \quad (2.12)$$

¹³The returns to scale are estimated with a translog LS model and are in the range from 0.86 to 1.19 for different groups of firms over the sample period.

¹⁴The share of variable capital is estimated as a nonlinear logistic function, described in more detail in Appendix.

where the shares of input costs in total costs, $C_{it} = F_{Lit}I_{it}$, are denoted by $\alpha_{Kit}^s = \frac{F_{Kit}K_{it}}{F_{Lit}I_{it}}$, $\alpha_{Lit}^s = \frac{F_{Lit}L_{it}}{F_{Lit}I_{it}}$ and $\alpha_{Mit}^s = \frac{F_{Mit}M_{it}}{F_{Lit}I_{it}}$ with the letter F_{it} denoting input prices and I_{it} total inputs. The variable capital is not directly observed in the data, so Roeger and Warzynski (2004) suggest to express its growth rate in terms of revealed productivity growth, Δx_{it} , and observable capital input, Δk_{it} . The growth rate of variable capital input is then defined as:

$$\Delta k_{it}^v = \varepsilon_{sx} \Delta x_{it} + \Delta k_{it} \quad (2.13)$$

Consider the output-based and price-based Solow residuals in (2.11) and (2.12), which are adjusted for the share of inputs in the total costs, and subtract them to obtain the following expression:

$$\begin{aligned} (\Delta q_{it} + \Delta p_{it}) - \alpha_{Lit}^s \Omega_{Lit}^s &= (1 - s_{it}) \alpha_{Kit}^s [(\Delta q_{it} + \Delta p_{it}) - (\Delta k_{it} + \Delta F_{Kit})] \\ &+ s_{it} \alpha_{Kit}^s \varepsilon_{sx} \Delta x_{it} \end{aligned} \quad (2.14)$$

where $\alpha_{Lit}^s \Omega_{Lit}^s = \alpha_{Kit}^s (\Delta k_{it} + \Delta F_{Kit}) + \alpha_{Lit}^s (\Delta l_{it} + \Delta F_{Lit}) + \alpha_{Mit}^s (\Delta m_{it} + \Delta F_{Mit})$. The left-hand side variable represents the subtraction of Solow residuals and the right-hand side represents the growth rate in revenues per capital weighted by the share of capital in total costs considering productivity of a firm i at time t . The testable model of the price-cost margins (μ_{it}) corrected for the variable capital is estimated by a system of seemingly unrelated equations containing revenue-based Solow residuals in Eq. (2.9) and cost-based Solow residuals in Eq. (2.14):

$$\begin{aligned} (\Delta q_{it} + \Delta p_{it}) - \sum_I \alpha_{Lit} \Delta F_{Lit} &= \mu_{it} [(\Delta q_{it} + \Delta p_{it}) - (\Delta k_{it} + \Delta F_{Kit})] \\ (\Delta q_{it} + \Delta p_{it}) - \alpha_{Lit}^s \Omega_{Lit}^s &= (1 - s_{it}) \alpha_{Kit}^s [(\Delta q_{it} + \Delta p_{it}) - (\Delta k_{it} + \Delta F_{Kit})] \\ &+ s_{it} \alpha_{Kit}^s \varepsilon_{sx} \Delta x_{it} \end{aligned} \quad (2.15)$$

5 Data

The firm-level data are derived from a commercial database Amadeus, collected by the consultancy Bureau van Dijk (van Dijk (2009)). The database consists of company accounts reported to national statistical offices for European companies. The advantage of using the company-accounts data is that prices generally determined by state regulators are based on accounting costs of services at the firm level (Fabrizio et al. (2007)).¹⁵ Table 1 presents the summary statistics of the variables retrieved from the company accounts. Data Appendix describes the definitions and measurement issues in construction of variables.

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

¹⁵I use long-term annual data, which is motivated by the availability of comparable data across countries and by the recent literature. Smeers (2005) points out that the relevant marginal cost is the long run marginal cost that is equal to the short run marginal cost when the generation system is optimally dimensioned. However, considering long-run marginal costs has the advantage that it smoothes the trajectory of short-run variations in capacities where prices are not sufficient to justify new investments (Smeers (2005)).

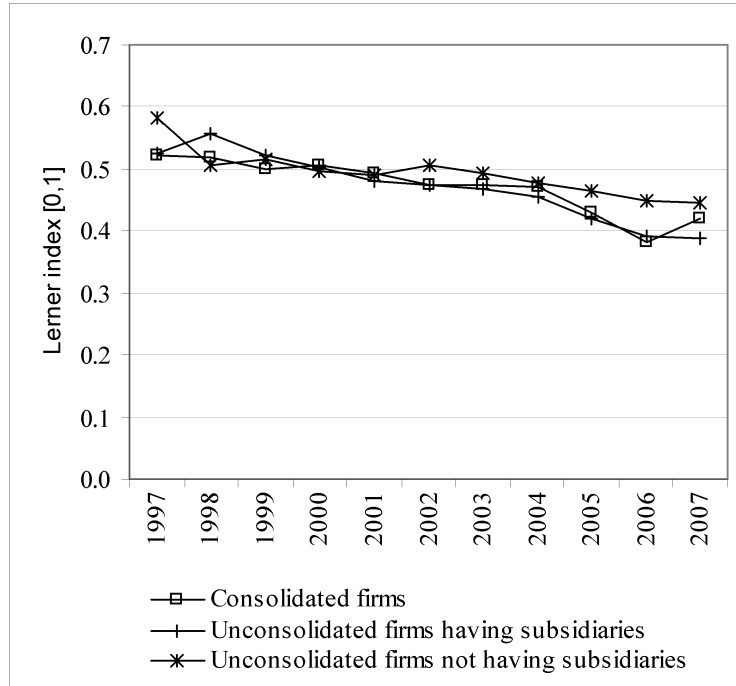
¹⁶The coverage of Amadeus data before 1996 and after 2007 is not representative for this sector, hence these time series are excluded from the analysis.

Table 1: Summary statistics

	PANEL 1			PANEL 2			PANEL 3		
	Consolidated firms having subsidiaries included in financials of parent firms)			Unconsolidated firms having subsidiaries (Subsidiaries excluded from financials of parent firms)			Unconsolidated firms not having subsidiaries		
	1997-2007	1997-2002	2003-2007	1997-2007	1997-2002	2003-2007	1997-2007	1997-2002	2003-2007
Number of firms	77	49	111	247	125	394	312	163	492
	(13.19)	(15.83)	(6.59)	(50.76)	(43.33)	(38.29)	(63.58)	(60.07)	(45.09)
Employment	2114	1739	2564	257	226	295	30	22	40
	(262.31)	(362.17)	(298.19)	(46.56)	(85.57)	(16.96)	(3.87)	(5.04)	(1.07)
Revenues (log)	16.04	15.66	16.49	13.99	13.46	14.64	12.59	12.53	12.67
	(0.17)	(0.21)	(0.11)	(0.27)	(0.39)	(0.03)	(0.05)	(0.09)	(0.05)
Capital costs (log)	11.32	11.01	11.69	8.73	8.34	9.20	7.21	7.33	7.06
	(0.13)	(0.12)	(0.09)	(0.23)	(0.37)	(0.02)	(0.08)	(0.12)	(0.05)
Labor costs (log)	9.26	8.97	9.61	7.15	6.76	7.62	5.49	5.53	5.45
	(0.15)	(0.21)	(0.10)	(0.22)	(0.33)	(0.02)	(0.04)	(0.07)	(0.04)
Material costs (log)	15.09	14.59	15.69	13.05	12.43	13.79	11.28	11.25	11.31
	(0.24)	(0.31)	(0.15)	(0.30)	(0.40)	(0.07)	(0.04)	(0.06)	(0.06)
Capital intensity	628	535	741	2778	2943	2580	2990	3766	2059
	(43.80)	(27.37)	(60.20)	(739.12)	(1346.65)	(516.20)	(1047.15)	(1930.59)	(206.46)
ROA	4.65	4.12	5.28	8.07	8.48	7.57	4.88	3.86	6.11
	(0.34)	(0.55)	(0.08)	(0.37)	(0.60)	(0.31)	(0.55)	(0.78)	(0.24)
Lerner index	0.47	0.50	0.44	0.47	0.51	0.42	0.49	0.52	0.47
	(0.01)	(0.01)	(0.02)	(0.02)	(0.01)	(0.02)	(0.01)	(0.01)	(0.01)

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 markups are reported in logarithms. Capital intensity (K/L) refers to total fixed assets over the number of employees. The Lerner index is calculated by the PCM method (Tybout 2003) as the value added over sales. ROA denotes returns on total assets. 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.

Figure 2: Evolution of Lerner index



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. Therefore, three sub-samples of firms are considered to define precisely the unit of observation in the empirical analysis. The reasoning for this split is that electricity firms are rather heterogeneous with respect to the scope and scale of their activities. The markup is likely to be determined at higher levels of organization and not at the level of subsidiaries. Subsidiaries are thus included only jointly in the first panel of consolidated firms, but not as individual units of observation in any of the three panels of firms considered in the analysis.

The first panel includes consolidated accounts of firms, which means that the subsidiaries are included in the financial data of parent firms. These firms are large legal entities with employment, revenues and input costs being the highest of all three panels. The second panel includes unconsolidated firms that have at least one subsidiary, but only the financial data of each individual firm are considered and not of subsidiaries. The third panel includes unconsolidated firms that do not have any subsidiaries. The firms in the third panel are typically small-sized electricity firms that generate, distribute and/or transmit electricity in a narrowly defined local market. The firms in the third panel are not direct subsidiaries of the firms in the second panel, but are individual undertakings operating in locally-specific markets.¹⁸

¹⁷The dataset includes ten countries across four major zonal markets, for which sufficient amount of comparable data are available from 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.

¹⁸Looking closer at Spanish economy, an example of consolidated firm with subsidiaries included in reported financials would be an internationally active Iberdola S.A., an example of unconsolidated firm having subsidiaries which are excluded from its financials would be Endesa Energia S.A., and an example for the third group would be a locally-specific unconsolidated firm Acciona Solaris Canarias SA, which is an independent firm operating only in

In principle, 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 within each of three groups that are in true competition within the markets defined. However, for these reasons, I do not expect to see much impact of liberalization for the third panel of firms in Table 1 due to their regional-specific character. Hence, the third panel of firms rather serves as a counterfactual group of firms whose markups are unlikely to be affected by EU-wide liberalization efforts, but instead more responsive to regionally-specific regulatory changes.

Descriptive statistics in Table 1 are further divided in three sub-samples with the last two columns referring to the period before and after the second EC Electricity Directive. The average Lerner index of around 0.47 suggests a rather oligopolistic market structure, since Lerner index is bounded between 0 and 1 with lower values representing higher degrees of competition. The first glance at the statistics on Lerner index reveals a decline of about 5 percentage points from period before and after the second EC electricity directive enforced in 2003. The smallest impact of liberalization efforts appears to be for unconsolidated firms that have no subsidiaries. Figure 5 plots Lerner index for three different groups of firms over time. There is a gradual decline over time, which is less pronounced for the third group of regionally-specific firms, as previously suggested by Table 1.

In what follows, I look for systematic evidence on whether this gradual decline in markups proxied by Lerner index has been associated with the liberalization efforts. The preliminary evidence above motivates further the analysis by implying downward pressure of European liberalization efforts on the price-cost margins of electricity firms. The choice of variables in the econometric section is motivated by this preliminary evidence. I will explicitly consider national and firm-specific measures of regulatory change and try to account adequately for electricity firms' attributes such as ownership and vertical integration of their activities.

6 Results

The results section follows conceptually the second section of this paper, referring to the institutional framework. To test whether the price-cost margins were affected by the institutional changes leading to fiercer competition, I first look at the price-cost margins and establish their link with main determinants of competitive pressure. As motivated by the previous literature at the beginning of this paper, I estimate the markup changes associated with cross-border arbitrage and market concentration.¹⁹ A further attention is paid to potential spatial autocorrelation. I consider that regional proximity of other electricity firms could matter and that firms can only supply electricity within an interconnected infrastructure grid that limits the scope of potential competition. All model specifications control for year and electricity activity specific effects and potential business cycle pressures on markups.

The first block of results determines an European-wide impact of EC liberalization directives on the markups of three different groups of firms, as defined by Table 1. This exercise is motivated

Canarias and does not report any subsidiaries.

¹⁹For example, Domowitz et al. (1988) were among the first to provide empirical evidence that concentration is positively related to price-cost margins. Konings and Vandenbussche (2005) and Vandenbussche and Zarnic (2008) among others show that markups may be negatively affected by import competition.

by the official EC document suggesting that further liberalization of European electricity markets through the second EC Directive would facilitate pro-competitive effects (Commission (2007a), Commission (2007b)). In the second block of results, I define carefully counterfactual measures of reform steps to verify that the price-cost margins have not declined after the second EC Electricity Directive due to a common electricity sector effect prevalent in all European countries. In the third block of results, I investigate the impact of privatization and unbundling on the markups by taking into account horizontal market concentration. I conclude by discussing robustness checks.

6.1 Impact of EU Liberalization Efforts on Markups

In the baseline specification, Eq. (2.10) is used in a log-linear LS model by applying annual fixed effects to control for any changes in markups that are common across firms.²⁰ I further make the standard assumption that is done in all applications of this type (see e.g. Levinsohn (1993), Konings et al. (2005), Van Biesebroeck (2007)), that the markups are invariant within the same group of firms. It is not possible to estimate a markup for each firm individually, because of not having sufficient degrees of freedom. To assess the impact of EC liberalization efforts, Δx_{it} is interacted with liberalization variable lib_t , which takes value 0 before 2003 and it is gradually increasing from 1 to 5 during 2003-2007. This variable is motivated by the official EC document suggesting that further liberalization of European electricity markets through the second EC Directive would gradually facilitate pro-competitive effects particularly from 2003 onwards Commission (2007a), Commission (2007b).²¹ The baseline regression model is then specified as:

$$\begin{aligned} \Delta y_{it} = & a_i + \mu_1 \Delta x_{it} + \beta_1 \Delta x_{it} \times lib_t \\ & + \beta_2 \Delta x_{it} \times \Delta m_{jt} + \beta_3 \Delta x_{it} \times \Delta h_{jt} + \beta_4 \Delta x_{it} \times \Phi_{it} + \beta_5 \Delta x_{it} \times \Delta gdp_{jt} \\ & + \beta_6 \Delta m_{jt} + \beta_7 \Delta h_{jt} + \beta_8 \Phi_{it} + \beta_9 \Delta gdp_{jt} + D_t \times G_i + \varepsilon_{it} \end{aligned} \quad (2.16)$$

where the dependent variable (Δy_{it}) represents the subtraction of Solow residuals and the parameters of the main interest are the average price-cost margin captured by the estimation coefficient μ_1 , while β_1 captures the effect of EU-wide liberalization on price-cost margins. The model also includes other potential determinants of price-cost margins. To assess the effect of increased cross-border arbitrage and market concentration on firms' price-cost margins, Δx_{it} is interacted with the electricity sector (j) trade arbitrage, T_{jt} , and market concentration, H_{jt} , at time t .²² The coefficients β_2 and β_3 indicate the change in price-cost margin associated with changes in trade arbitrage (Δm_{jt}) and market concentration (Δh_{jt}).

In all specifications with interaction effects, the main effects of variables are included to exclude the possibility that main effects and interaction effects are confounded (referring to coefficients from β_6 to β_9). A set of controls such as real growth of GDP (Δgdp_{jt}) and year dummies D_t control for business cycles and macro effects common across firms over time. Market liberalization may

²⁰Following the results of the Hausman test I prefer a fixed-effects model over a random-effects model. The F-test indicated that fixed effects were significant in all model specifications. I control for business cycles with the real GDP growth rates to proxy for country-level shifts of demand as in Vandenbussche and Zarnic (2008). The Appendix describes the data and variables in more detail.

²¹The mechanism of EU legislation is explained comprehensively in Section 2. I have also experimented with different measures of EU-wide liberalization progress, but did not observe any substantial impact on the markups during the first electricity directive.

²²I measure trade arbitrage as imports over imports and sales of electricity output of country k at time t , similar to Vandenbussche and Zarnic (2008). Market concentration is proxied by Herfindahl index as the sum of the squares of the market shares of each individual firm computed at the 3-digit electricity sector for country-year pairs.

have a different impact on power generating firms than on transmission or distribution firms. I account for heterogeneity of these three types of electricity firms by including a dummy variable distinguishing them in econometric estimations, which is interacted with year effects ($D_t \times G_i$) to obtain a time-variant measure. The coefficient a_i is an unobservable firm-level fixed effect, which may capture unobserved sunk costs, quality of the managers, and other fixed factors I may not observe (as in Konings et al. (2005)).

6.1.1 Regional Proximity

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. I address this issue in two ways. First, I impose the structure on the error term by clustering firms according to pertinent zonal markets capturing dyads of regions, which share an interconnected infrastructure grid. Second, I introduce a control variable that captures the effect of regional proximity of firms on their markups, denoted by Φ_{it} in (2.16).

For this purpose, I use information on a firm’s activity in a certain geographical region of each country. Since I do not have the data on exact geographical distances between all regions of firms’ origin, I construct a proxy measure of regional proximity. First, I calculate a deviation of each firm’s Lerner index from the average Lerner index of countries’ regions in a certain year. This variable is then interacted with Δx_{it} , so that β_4 gives the effect of regional proximity on the markup. The latter approach implicitly assumes that competition intensifies with more firms closer one to another. Second for robustness reasons, I define regional proximity as a vector of regional weights, identifying the firms sharing the same regions. Both measures of regional proximity yield an intuitive result that the average markups decrease with geographical proximity of firms. These approaches are motivated by the literature on spatial autocorrelation in network industries.²³

6.1.2 Baseline Results

Table 2 reports the estimation results of the baseline model specified by (2.10) for three groups of firms. The average price-cost margin is estimated at almost 45% for the largest consolidated firms in column (1), 42% for unconsolidated firms having subsidiaries in column (2), and the lowest markups of 37% for the group of unconsolidated firms not having any subsidiaries in column (3). These point estimates are roughly compared to the recent evidence by the Commission (2007a), Commission (2007b). Their report documents a large variation in terms of price-cost margins across six European countries, ranging from 31% for the UK to 51% for Germany during 2003-2005. In contrast to their study, I do not have comparable data for the UK but I include a larger sample of ten countries for a longer period of 1997-2007, as described in Data Appendix.

The level of price-cost margin is relatively high, which confirms the view of Smeers (2005) that the level of competition in the European electricity sectors remains unsatisfactory as the integration of national electricity systems into a single internal European electricity market is not progressing

²³As discussed by Fischer and Griffith (2008) autocorrelation is attributable to the configurational arrangement of observations and the problem might arise in situations where the observations are non-independent over space with nearby spatial regions associated in some way. An alternative approach could be to directly model spatial autocorrelation among flow residuals by introducing a spatial error structure reflecting origin and destination autoregressive dependence among origin–destination flows, as proposed by Fischer and Griffith (2008). This measure is not possible to construct with the data on electricity firms, because there is very scarce information on destinations of electricity purchases.

Table 2: Baseline results: Effect of EU liberalization efforts on markups

	Consolidated firms having subsidiaries (1)	Unconsolidated firms having subsidiaries (2)	Unconsolidated firms not having subsidiaries (3)
Markup	0.446 (0.036)***	0.419 (0.024)***	0.374 (0.022)***
Effect of liberalization	-0.018 (0.009)**	-0.030 (0.004)***	-0.002 (0.004)
Effect of cross-border arbitrage	-0.019 (0.006)***	-0.025 (0.005)***	-0.007 (0.004)*
Effect of market concentration	-0.002 (0.001)	0.007 (0.002)***	-0.002 (0.001)
Effect of regional proximity	-0.071 (0.034)**	-0.037 (0.018)**	-0.056 (0.016)***
Effect of GDP	-0.070 (0.018)***	-0.076 (0.013)***	-0.004 (0.012)
Interacted terms in nominal terms	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes
Clustered by zones with interconnected grid	Yes	Yes	Yes
R-sq.	0.420	0.291	0.393
Observations	798	2612	3262

Notes: Robust standard errors (in brackets) from the ordinary-least squared regressions are corrected for autocorrelation and heteroskedasticity by considering spatial dimension according to the zonal market with interconnected infrastructure grid within which the firms operate; ***, **, * denote respectively statistical significance at 1%, 5% and 10%. The main effects of the variables used to compute the interaction terms are included to exclude the possibility that main effects and interaction effects are confounded, but are not displayed for brevity. The validity of the regression model is confirmed by the F-test in all specifications. Construction of variables is described in Appendix.

fast. The results further indicate that the markups have declined due to EU-wide liberalization efforts in the order of 2 percent each year from 2003 onwards for consolidated firms in column (1) and 3 percent for unconsolidated firms having subsidiaries in column (2), which is consistent with a decline in Lerner index shown by Figure 5. As expected, the EU-wide liberalization has not affected the markups of regionally-specific unconsolidated firms having no subsidiaries in column (3).

In line with previous sections, the price-cost margins are negatively associated with cross-border arbitrage and positively associated with market concentration.²⁴ On the one hand, highly concentrated sectors reflect less competitive pressure, which allows firms to exert a certain degree of their monopoly power reflected in higher price-cost margins.

These effects are particularly strong for firms in column (2) of Table 2. The negative coefficient -0.02 in column (2) suggests that an increase in arbitrage of 10 percentage points is equivalent to a decline in the average price-cost margin of 2 percentage points. The estimate of 0.01 in column (2) suggests that an increase in market concentration of 10 percentage points is equivalent to an increase in the average price-cost margin of 1 percent. The measure of regional proximity yields an intuitive result that the average markups decrease with geographical proximity of firms,

²⁴The average Herfindahl index (HHI) calculated with the data is on average rather low at 15% and has gradually dropped from 43% in 1995 to 12% in 2007. As discussed by Smeers (2005), in restructured electricity markets even companies with very small market share can exert significant market power. Import penetration is on average around 68% with the large variation across the sample of countries, ranging from 2% for Norway and 98% for Luxembourg, which in contrast to Norway imports most of its electricity from neighboring countries.

particularly for large consolidated firms (1) and regionally-specific unconsolidated firm having no subsidiaries (3).

Although indicative and economically intuitive, the orders of magnitude presented here have to be interpreted with caution, since a rather low R^2 indicates that some variance in the data is unexplained by the model. In the previously described Roeger method the measurement errors theoretically equal zero, however the following reasoning sheds some light why measurement errors might not disappear in differences of Solow residuals.

A possible explanation lies in construction of the capital variable. It is customary to measure the rental price of capital through the definition of rental price of capital using the appropriate nominal after-tax interest rate proxied by a long-term real interest rate, expected rate of change in price of capital good and price of capital goods (e.g. see Martins et al. (1996), Konings and Vandenbussche (2005), Konings et al. (2005) formulated as $Z_{jt}(r_{kt} + d_{jt})$ with a country-level price index of investment goods (Z_{jt}), a long-term real interest rate (r_{kt}) at time t for country k , and depreciation of capital (d_{jt}).

This measure is the best approximation one can get from the data, but it might depart somewhat from the true rental price of capital for the following reasons discussed by Forsman et al. (1996). The financing sources differ across firms and over time, so that a long bond yield cannot describe well the nominal cost of capital, which in turn could also be influenced by corporate taxation. Therefore, the correct deflator is not the immediate behavior of any aggregate price index, but rather of expected behavior of the price of a particular capital good over a long-term investment plan. Consequently, Forsman et al. (1996) show that the Roeger method will produce consistently higher estimates of markup levels and lower estimates of changes in markups.

6.2 Counterfactual Measures of Institutional Reforms

In this sub-section, I look for counterfactual measures of regulatory change to verify that the price-cost margins have not declined after the second EC Electricity Directive due to a common electricity sector effect prevalent in all European countries. I use all available information from the national and external sources to construct the variables that are in line with the economic intuition discussed in the recent literature, which is presented in the previous sections. Detailed descriptions of variables and sources are provided in Appendix. The econometric specification is defined in a similar way as previously in Eq. (16), but instead of an EU-wide liberalization measure (lib_t) I consider sequentially the measures of regional-specific institutional reforms (R_{jt}):

$$\begin{aligned} \Delta y_{it} = & a_i + \mu_1 \Delta x_{it} + \beta_1 \Delta x_{it} \times R_{jt} \\ & + \beta_2 \Delta x_{it} \times \Delta m_{jt} + \beta_3 \Delta x_{it} \times \Delta h_{jt} + \beta_4 \Delta x_{it} \times \Phi_{it} + \beta_5 \Delta x_{it} \times \Delta gdp_{jt} \\ & + \beta_6 \Delta m_{jt} + \beta_7 \Delta h_{jt} + \beta_8 \Phi_{it} + \beta_9 \Delta gdp_{jt} + D_t \times G_i + \varepsilon_{it} \end{aligned} \quad (2.17)$$

where the parameter of the main interest is β_1 that captures the effect of a specific institutional measure on the price-cost margin. I estimate several different models, including each time a different measure of institutional reform. The choice of measures is motivated directly by Section 2 and builds upon the same data used in figures presented there. The rest of variables are the same as in Table 2. Table 4 presents the results of different model specifications in rows for three groups of firms in columns. All specifications use Eq. (2.17), but for presentation purposes the focus lies on the effect of each institutional measure on the price-cost margin while omitting the

Table 3: Baseline results: Location-specific measures of liberalization

	Consolidated firms having subsidiaries (1)	Unconsolidated firms having subsidiaries (2)	Unconsolidated firms not having subsidiaries (3)
Model 1: National liberalization act			
Markup	0.445 (0.050)***	0.415 (0.027)***	0.367 (0.026)***
Markup * reform	-0.018 (0.006)***	-0.023 (0.003)***	-0.000 (0.003)
Model 2: Operational authority			
Markup	0.430 (0.045)***	0.419 (0.022)***	0.345 (0.022)***
Markup * reform	-0.018 (0.006)***	-0.028 (0.003)***	0.003 (0.003)
Model 3: Wholesale market opening			
Markup	0.462 (0.043)***	0.450 (0.027)***	0.481 (0.024)***
Markup * reform	-0.084 (0.019)***	-0.111 (0.014)***	-0.026 (0.013)**
Model 4: Retail market opening (only for industrial use)			
Markup	0.445 (0.050)***	0.467 (0.024)***	0.469 (0.025)***
Markup * reform	-0.020 (0.007)***	-0.035 (0.003)***	-0.016 (0.003)***
Model 5: Retail market opening (for industrial and household use)			
Markup	0.434 (0.035)***	0.338 (0.023)***	0.400 (0.019)***
Markup * reform	-0.007 (0.004)	-0.034	-0.025 (0.003)***
Model 6: Unbundling			
Markup	0.391	0.367 (0.023)***	0.360 (0.020)***
Markup * reform	-0.090 (0.027)***	-0.007 (0.017)	-0.015 (0.011)
Model 6: Reducing regulatory burden (OECD index)			
Markup	0.405 (0.034)***	0.334 (0.024)***	0.346 (0.020)***
Markup * reform	-0.059	-0.167 (0.027)***	-0.092 (0.024)***

Notes: All models include the same set of other variables as in Table 1, but are not displayed to save space. Robust standard errors (in brackets) from the ordinary-least squared regressions are corrected for autocorrelation and heteroskedasticity by considering spatial dimension according to the zonal market with interconnected infrastructure grid within which the firms operate; ***, **, * denote respectively statistical significance at 1%, 5% and 10%. The validity of the regression model is confirmed by the F-test in all specifications. Construction of variables is described in Appendix.

Table 4: Baseline results: Effect of ownership on markups

	Unconsolidated firms having subsidiaries			Unconsolidated firms not having subsidiaries		
	(1)	(2)	(3)	(4)	(5)	(6)
Markup	0.358 (0.023)***	0.253 (0.036)***	0.363 (0.023)***	0.357 (0.019)***	0.377 (0.037)***	0.366 (0.019)***
Markup * HHI * privatization (<i>OECD index of state ownership</i>)	-0.003 (0.001)***	-	-	-0.005 (0.001)***	-	-
Markup * HHI * privatization (<i>Firm-level measure of private ownership</i>)		-0.061 (0.008)***			-0.084 (0.101)	
Markup * HHI * bundling (<i>Firm-level measure of vertical integration</i>)			0.034 (0.012)***			0.012 (0.013)
Effect of cross-border arbitrage	-0.024 (0.005)***	-0.007 (0.008)	-0.021 (0.005)***	-0.007 (0.004)	-0.010 (0.008)	-0.006 (0.004)
Effect of market concentration (HHI)	0.006 (0.002)***	0.056 (0.007)***	0.039 (0.011)***	-0.001 (0.001)	0.075 (0.101)	0.010 (0.012)
Effect of GDP	-0.091 (0.013)***	-0.007 (0.019)	-0.088 (0.013)***	-0.011 (0.012)	-0.034 (0.020)*	-0.003 (0.012)
Interacted terms in nominal terms	Yes	Yes	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes
Clustered by zones with interconnected grid	Yes	Yes	Yes	Yes	Yes	Yes
R-sq.	0.285	0.317	0.280	0.398	0.336	0.393
Observations	2612	1067	2612	3262	914	3262

Notes: Robust standard errors (in brackets) from the ordinary-least squared regressions are corrected for autocorrelation and heteroskedasticity by considering spatial dimension according to the zonal market with interconnected infrastructure grid within which the firms operate; ***, **, * denote respectively statistical significance at 1%, 5% and 10%. The main effects of the variables used to compute the interaction terms are included to exclude the possibility that main effects and interaction effects are confounded, but are not displayed for brevity. The validity of the regression model is confirmed by the F-test in all specifications. Construction of variables is described in Appendix.

presentation of other variables for brevity.

A *de jure* policy in Model (1), measured by the number of years from the establishment of national electricity liberalization act, and *de facto* operating time of the authority (Model 2) assigned to its implementation are expected to enhance market competitiveness reflected by lower markups. The results suggest that the longer in time the national authority operates, the lower the markups. While the effect is comparable across the first two groups of firms, it is not statically significant for the third group of firms (3). Models (3) to (5) capture the effect of wholesale and retail market functioning on the price-cost margins. Intuitively, a better access to the wholesale and retail markets would foster competitive behavior on demand and supply sides of the market. I expect that pro-competitive effect would lead to lower markups.

Consistently the results indicate that price-cost margins are negatively associated with better functioning of wholesale and retail markets. The retail market access effect is dominantly driven by the ability of large industrial consumers to switch between electricity providers for the group of consolidated firms in column (1) of Table 3. To give further insights about the strictness of institutional market barriers, I refer to the OECD indices of vertical integration and regulatory burden in the last rows. Note that the OECD indicators are inverted, so that higher values refer to greater competition.

The annual decrease in vertical integration negatively affects only the markups of consolidated firms in column (1) of Table 3. This suggests that greater market foreclosure due to vertical integration of transmission and distribution channels is significantly related to higher markups of the largest consolidated firms. However, their markups do not seem to be affected by decreasing

overall regulatory burden in the market, while it matters for the other two groups. Intuitively, high regulatory constraints such as entry barriers and rigid financial contracts captured by the last measure prevent new entry and to a certain degree condition less-competitive behavior reflected by high price-cost margins.

6.3 Privatization, Unbundling and Horizontal Concentration

Joskow (1997) among others points out that production of electricity used to rely intensively on public or private monopoly suppliers, whose strategic behavior has been regulated by governments. The cost-inefficient storage of electricity and limited interconnection capacities have favored vertically integrated firms in concentrated markets. Damijan et al. (2005), Damijan and Knell (2005) and Konings et al. (2005) further suggest that privatization could lead to more competitive outcomes as the changes in ownership structure improve the performance of firms, however conditional on the prevailing market concentration. Their studies motivate the choice of the ownership variables and guide interpretation of the results in line with economic intuition presented in Section 2.

To estimate the markup effect of firm-level private ownership and unbundling conditional on horizontal market concentration, I interact Δx_{it} with measure of market concentration (Δh_{jt}) and measure of private ownership or bundling. This information is sequentially captured by a dummy variable v_{it} , taking value 1, if a firm is private-owned and alternatively, if it bundles transmission and distribution channels, and 0 otherwise. Since firm-level ownership data is rather scarcely reported in the data source and the effects may be affected by a truncated sample, I compare the results based on firm-level and country-level ownership. The country-level measure of privatization is based on the OECD index of state ownership. The estimated regression is:

$$\begin{aligned} \Delta y_{it} = & a_i + \mu_1 \Delta x_{it} + \beta_1 \Delta x_{it} \times \Delta h_{jt} \times v_{it} \\ & + \beta_2 \Delta x_{it} \times \Delta m_{jt} + \beta_3 \Delta x_{it} \times \Delta h_{jt} + \beta_4 \Delta x_{it} \times \Phi_{it} + \beta_5 \Delta x_{it} \times \Delta gdp_{jt} \\ & + \beta_6 \Delta m_{jt} + \beta_7 \Delta h_{jt} + \beta_8 \Phi_{it} + \beta_9 \Delta gdp_{jt} + D_t \times G_i + \varepsilon_{it} \end{aligned} \quad (2.18)$$

where the rest of explanatory variables resemble the variables used in (2.16). Table 4 presents the results for two groups of firms, but not for the group of consolidated firms, because most of them are vertically integrated firms with mixed private and state ownership. Looking at the firm ownership in columns (1) to (2), I find that private-owned firms exhibit lower markups if market concentration of the incumbent firms is high.²⁵ A negative coefficient of 0.03 in column (3) suggests that vertically integrated firms exhibit much higher markups in concentrated markets. The effects of firm-specific measures of ownership and bundling are statistically significant only for the group of unconsolidated firm having subsidiaries.

6.4 Robustness Checks

6.4.1 Alternative Model Specification

An alternative model specification is used to consider firms' allocation of capital assets as defined by Eq. (2.15). This method provides an alternative way to estimate the price-cost margins by

²⁵The regression results using ownership status are based on lesser observations, because I drop from the analysis those firms for which I could not trace ownership information in the Amadeus data. This ensures that the information I use is a good measure of whether a firm is private-owned or not.

Table 5: Robustness checks with the variable capital model: Effect of EU liberalization efforts on markups

	Consolidated firms having subsidiaries (1)	Unconsolidated firms having subsidiaries (2)	Unconsolidated firms not having subsidiaries (3)
Markup	0.439 (0.035)***	0.416 (0.024)***	0.365 (0.021)***
Effect of liberalization	-0.025 (0.008)***	-0.029 (0.004)***	-0.002 (0.004)
Effect of cross-border arbitrage	-0.019 (0.006)***	-0.026 (0.005)***	-0.007 (0.004)
Effect of market concentration	-0.001 (0.001)	0.008 (0.002)***	-0.002 (0.001)
Effect of regional proximity	-0.053 (0.033)	-0.035 (0.018)*	-0.054 (0.016)***
Effect of GDP	-0.057 (0.018)***	-0.076 (0.013)***	-0.001 (0.012)
Interacted terms in nominal terms	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes
Clustered by zones with interconnected grid	Yes	Yes	Yes
R-sq.	0.412	0.288	0.391
Observations	798	2612	3262

Notes: Robust standard errors (in brackets) from the ordinary-least squared regressions are corrected for autocorrelation and heteroskedasticity by considering spatial dimension according to the zonal market with interconnected infrastructure grid within which the firms operate; ***, **, * denote respectively statistical significance at 1%, 5% and 10%. The main effects of the variables used to compute the interaction terms are included to exclude the possibility that main effects and interaction effects are confounded, but are not displayed for brevity. The validity of the regression model is confirmed by the F-test in all specifications. Construction of variables is described in Appendix.

maintaining the hypothesis that marginal costs and marginal revenues are unobservable and thus price-cost margins are estimated using the notion of total factor productivity.²⁶

Table 5 documents that the estimates of price-cost margins are not sensitive with respect to an alternative model specification. In particular, I try to account for the part of markup related to a scarcity rent utilization $r_{it}(q_{it})$ in Eq. (2.3). The results from the variable capital model estimated by (2.15) in columns (1) to (3) are consistent with the theory. The consideration of capital asset allocation is associated with somewhat lower markups in the order of 1 percentage point. This is largely due to data observations that on average more than 90 percent of capital is fixed in the electricity sector. The effect of EU-wide liberalization is significant for the first two groups of firms in the order of 2 percent-decrease in markups per year, as observed also in Table 2. The sample size and the rest of explanatory variables are also the same as in Table 2 and yield similar results in Table 5.

The results above imply that the price-cost margins are on average still relatively high across

²⁶The variable capital approach steps aside from the price-cost margin (PCM) method applied to the electricity sector among others by Joskow and Schmalensee (1983), Wolfram (1999) and Wolak (2003). This strand of literature argues that the production technology in the electricity sector is straightforward and well understood and thus marginal costs can be directly computed on the basis of the input costs and generated output. As the second alternative, I have experimented with the PCM model that gave similar results (as shown by Figure 5) and is thus not presented here for brevity. As the third alternative, I have borrowed a concept developed by Olley and Pakes (1996) to correct the price-cost margins for productivity shocks with an instrument that includes a polynomial of input costs. This method also gave similar results, but I found it less suitable because it severely truncated the sample due to its requirement of non-negative capital values over consecutive years.

Table 6: Robustness checks with the variable capital model: Location-specific measures of regulatory change

	Consolidated firms having subsidiaries (1)	Unconsolidated firms having subsidiaries (2)	Unconsolidated firms not having subsidiaries (3)
Model 1: National liberalization act			
Markup	0.467 (0.048)***	0.410 (0.027)***	0.361 (0.026)***
Markup * reform	-0.021 (0.006)***	-0.023 (0.003)***	-0.000 (0.003)
Model 2: Operational authority			
Markup	0.445 (0.043)***	0.414 (0.022)***	0.341 (0.022)***
Markup * reform	-0.020 (0.005)***	-0.027 (0.003)***	0.003 (0.003)
Model 3: Wholesale market opening			
Markup	0.450 (0.041)***	0.444 (0.027)***	0.464 (0.023)***
Markup * reform	-0.012 (0.006)**	-0.017 (0.003)***	-0.018 (0.002)***
Model 4: Retail market opening (only for industrial use)			
Markup	0.461 (0.048)***	0.463 (0.024)***	0.457 (0.024)***
Markup * reform	-0.023 (0.006)***	-0.035 (0.003)***	-0.015 (0.003)***
Model 5: Retail market opening (for industrial and household use)			
Markup	0.413 (0.034)***	0.334 (0.022)***	0.391 (0.019)***
Markup * reform	-0.007 (0.004)	-0.034 (0.003)***	-0.024 (0.002)***
Model 6: Unbundling			
Markup	0.367 (0.023)***	0.353 (0.019)***	0.396 (0.032)***
Markup * reform	-0.088 (0.026)***	-0.003 (0.017)	-0.014 (0.011)
Model 6: Lower regulatory burden (OECD index)			
Markup	0.387 (0.033)***	0.330 (0.023)***	0.340 (0.020)***
Markup * reform	-0.048 (0.053)	-0.169 (0.027)***	-0.085 (0.024)***

Notes: All models include the same set of other variables as in Table 1, but are not displayed to save space. Robust standard errors (in brackets) from the ordinary-least squared regressions are corrected for autocorrelation and heteroskedasticity by considering spatial dimension according to the zonal market with interconnected infrastructure grid within which the firms operate; ***, **, * denote respectively statistical significance at 1%, 5% and 10%. The validity of the regression model is confirmed by the F-test in all specifications. Construction of variables is described in Appendix.

Table 7: Robustness checks: A balanced panel of firms

	Consolidated firms having subsidiaries (1)	Unconsolidated firms having subsidiaries (2)	Unconsolidated firms not having subsidiaries (3)
Markup	0.418 (0.052)***	0.353 (0.035)***	0.439 (0.027)***
Effect of liberalization	0.012 (0.015)	-0.020 (0.006)***	0.005 (0.005)
Effect of cross-border arbitrage	-0.023 (0.008)***	-0.033 (0.008)***	-0.011 (0.005)**
Effect of market concentration	-0.003 (0.002)	0.010 (0.003)***	-0.003 (0.002)
Effect of regional proximity	-0.165 (0.053)***	0.030 (0.027)	-0.103 (0.021)***
Effect of GDP	-0.060 (0.028)**	-0.046 (0.022)**	-0.013 (0.016)
Interacted terms in nominal terms	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes
Clustered by zones with interconnected grid	Yes	Yes	Yes
R-sq.	0.522	0.329	0.444
Observations	469	1476	1932

Notes: Robust standard errors (in brackets) from the ordinary-least squared regressions are corrected for autocorrelation and heteroskedasticity by considering spatial dimension according to the zonal market with interconnected infrastructure grid within which the firms operate; ***, **, * denote respectively statistical significance at 1%, 5% and 10%. The main effects of the variables used to compute the interaction terms are included to exclude the possibility that main effects and interaction effects are confounded, but are not displayed for brevity. The validity

the sample of countries. As discussed in the previous literature (e.g. Jamasb and Pollitt (2005) and Roeller et al. (2007)), this is likely due to regulatory constraints, insufficient unbundling and limited cross-border trade of electricity due to the existing interconnection grid. Table 6 presents the results on region-specific regulatory changes to investigate their impact on the price-cost margins of electricity firms. The results from the variable capital model in Table 6 come close to the ones from the baseline model in Table 4, which adds to the robustness of the results. The above results are consistent with the theoretical literature and imply a gradual decline in markups associated with industry restructuring. In particular, the results give support for theoretical models emphasizing the complementarity and sequencing of reforms that gradually increase competitive pressure (see e.g. Dewatripont and Roland (1992), Dewatripont and Roland (1995)).

6.4.2 Sample Selection

Additional robustness checks are presented in Table 7 to verify the selection of the sample and validity of the results. Following Eq. (2.10) I first check whether the results in Table 2 are influenced by using a balanced panel of continuing firms over the sample period. Using a balanced panel may result in a selection bias, because no allowance is made for entry and exit.²⁷ Comparing the results of the balanced and unbalanced sample for the fixed-effects estimator enables us to determine whether this estimator adequately corrects for the selection bias, that is, whether exit

²⁷This robustness check is motivated by Van Biesebroeck (2007), Van Biesebroeck (2008).

decisions at the firm level are only determined by the time-invariant firm-specific effects.

Comparing the results in the first row of Table 7 to the first row of Table 2, the ranking of markups still holds for the first two groups of firms. However, for the last group of firms the markup appears to be higher than observed in Table 2, which is likely due to a rather unbalanced panel of these firms over time (i.e. 1932 observations in Table 7 compared to 3262 in Table 2). The effect of EU-wide effect of liberalization is highly statistically significant only for the second group of unconsolidated firms having subsidiaries. The effect of regional proximity still holds strongly for the first group of consolidated firms and the third group of firms without any subsidiaries. The rest of effects are similar to the results presented in Table 2. On average, the results appear to be rather robust to sample selection issues. I have also experimented with alternative model specifications as described in the previous sub-section. The results from alternative models were similar to the ones presented in Table 7 and are here omitted for brevity.

7 Conclusion

This paper has presented a number of estimates of price-cost margins and their relationship with economic integration of European electricity systems towards a single European market. The results are in line with the theoretical literature and imply a gradual decline in markups associated with liberalization and restructuring of the electricity sector. I find that greater openness to cross-border trade, better access to wholesale and retail markets and privatization in concentrated markets are associated with a decline in markups. By contrast, greater market concentration and bundling of transmission and distribution channels are associated with higher markups.

Exploiting the variation in staging of institutional reforms across different European countries, this paper provides robust firm-level evidence of their impact on the price-cost margins of European electricity firms. The purpose of this study is to focus on direction of the effect of liberalization efforts on the markups, rather than to provide point-estimates of markup levels. Although economically intuitive, the orders of magnitude have to be interpreted with caution in line with assumptions taken in the empirical model.

An effective economic integration of the European electricity systems would on average definitely reduce the markups of incumbents (Smeers (2005)). This would be in line with the internal market principle that competition would develop as a result of the economic integration, which would in turn reduce the markups of even the largest incumbent firms. However, I find that in spite of the EC liberalization efforts, the electricity firms on average still exhibit considerable price-cost margins of about 40 percent. Nonetheless, the estimated markups appear to be larger than most theoretical models would predict (Wolfram (1999), Borenstein et al. (2002) and Bushnell et al. (2008)).

In conclusion, the findings confirm the discussions in the previous literature about the sluggish progress of the integration process, which is mainly due to inadequate harmonization measures, insufficient unbundling and limited cross-border trade that are needed to foster competition and reduce the market power of firms (Jamاسب and Pollitt (2005), Smeers (2005) and Roeller et al. (2007). Smeers (2005) further notes that the economic integration can be achieved by ex-ante policy instruments improving transmission and balancing in the European electricity system.

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8 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 (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 am 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 1995-2007. 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 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.

The capital variable is defined in line with Konings and Vandebussche (2005) as the user cost of capital multiplied by its nominal value. The user value of capital is defined as $Z_{jt}(r_{kt} + d_{jt})$ with a country-level price index of investment goods Z_{jt} , a long-term real interest rate r_{kt} at time t for country k , and depreciation of capital, d_{jt} , of the average rate of 15 percent which is in line with the Commission (2007a), Commission (2007b) stating that the average depreciation of capital in the electricity sector for EU15 lies between 10 and 20 percents. I simulated the sensitivity of price-cost margins towards different depreciation rates, price indices of investment goods, and real interest rates. Allowing for 5 percent changes, the point estimates vary within the range of 1 percent, without altering the signs of estimated coefficients.

Firm-specific bundling is a firm-level measure computed by using the information from Amadeus on the secondary industrial activities of each firm. It is a dummy variable taking value 1, if a firm reports its presence in both transmission and distribution of electricity. The variable captures strictly the bundling of electricity transmission and distribution at the firm-level. The information on ownership is collected directly from the companies and retrieved from Amadeus database, which receives information from its providers from all European countries. This information is analyzed to identify each cross-border holding or subsidiary link by the national identification number of the companies involved. Besides the percentage share of direct owners, the ownership status also comprises information about the nationality of the ownership, private and foreign. The regressions using ownership status are based on lesser observations, because I drop from the analysis those firms for which I could not trace ownership information in the Amadeus data. This ensures that

the information used provides a good measure of whether a firm is domestically privately owned, foreign-owned or state-owned. The ownership status does not vary and refers to the latest data collected, because the ownership status is only recorded at the time that the data are collected by Bureau Van Dyk. I therefore used two different CD-ROMS, the one referring to the data collected in the year 2007 and the other referring to the data collected in 2009 to trace the changes in ownership status.

Market concentration in the regression analysis is measured by the Herfindahl index, which is the sum of squared market share of firms in a given three-digit Nace Rev.1.1 industry. Time-series of the market share of the largest firm in the electricity sector are retrieved from the Eurostat structural data for the energy sector. The measure of availability of generator plants is computed as the share of electricity output provided by each type of generators in the total electricity output per each country and year, based on the Eurostat structural data on energy sector. The measure of trade arbitrage is the ratio of imports to the sum of domestic sales and imports in a given three-digit industry, based on the product-level trade data from Eurostat External Trade Database.

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), Commission (2007b)). The measure of national legislation refers to the date of implementation of the first national Electricity Act. 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 Mibex 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 measures 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 10-30% (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 this study the values of OECD indices are inverted, 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, Reg-

ulatory 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) and updated by OECD (2009).

9 Annex B: The Baseline Model

The firm-specific price markup over marginal cost is derived by following the approach developed by Roeger (1995) and among others applied by Konings and Vandembussche (2005) and Vandembussche and Zarnic (2008) to the firm-level data. Similar to Hall (1988), consider a log-linear homogeneous production function $Q_{it} = G(K_{it}, L_{it}, M_{it})E_{it}$ for output Q_{it} , where K_{it} , L_{it} , and M_{it} are capital, labor and material inputs, and E_{it} is a shift variable representing changes in productivity efficiency of a firm i at time t . This consideration is standard in literature (e.g. Hall (1988), Olley and Pakes (1996), Fabrizio et al. (2007), so that the function is of Cobb-Douglas type: $Q_{it} = G(K_{it}, L_{it}, M_{it})E_{it}$ or $Q_{it} = \exp(e_{it})K_{it}^{\alpha_K} L_{it}^{\alpha_L} M_{it}^{\alpha_M}$.

In order to account for simultaneity bias coming from the correlation between the TFP growth and production inputs, Hall (1988) uses instruments. The aggregate instruments are not plausible in the firm-level analysis, because there is no variation across firms and valid firm-level instruments are not available in the data. Roeger (1995) circumvents this issue by subtracting the price-based from the output-based Solow residual, which leads to cancelation of the residual TFP term. Using the Solow residual (SR_{it}), Hall (1988) measures the productivity growth as the output growth net weighted growth of the production factors, described as:

$$SR_{it} = \Delta q_{it} - (\xi_{it} - \alpha_{Lit} - \alpha_{Mit}) \Delta k_{it} - \alpha_{Lit} \Delta l_{it} - \alpha_{Mit} \Delta m_{it} + \Delta e_{it} \quad (\text{B.1})$$

where small letters refer to the logarithms and ξ_{it} denotes economies of scale parameter. Equation (B.1) considers the share of inputs in the firm operating revenues, where the shares of labor and material costs in total revenues ($P_{it}Q_{it}$) of a firm i at time t are denoted by $\alpha_{Lit} = \frac{F_{Lit}L_{it}}{P_{it}Q_{it}}$ and $\alpha_{Mit} = \frac{F_{Mit}M_{it}}{P_{it}Q_{it}}$ with the letters F and P denoting input and output prices. Decomposition of the markup and the technology component is a crucial step in the Roeger approach and (B.1) can be expressed in the following form:

$$SR_{it} = \mu_{it}(\Delta q_{it} - \Delta k_{it}) + (\xi_{it} - \mu_{it}) \Delta e_{it} \quad (\text{B.2})$$

where $\mu_{it} = \frac{P_{it} - c_{it}}{P_{it}}$ is the Lerner index for a firm i at time t . The right-hand side is decomposed in the markup and the pure technology component.²⁸ In the output-based residual SR_{it} , the growth of firm's i revenues is denoted by Δq_{it} and the growth rate of capital by Δk_{it} at time t . Similarly in the price-based residual SRP_{it} , the growth rates of capital costs and output prices are respectively denoted by ΔF_{Kit} and Δp_{it} . The price-based or the dual Solow residual (SRP_{it}) is then defined from the relationship between the marginal cost and the output price and it can be expressed in the following form:

$$\begin{aligned} SRP_{it} &= (\xi_{it} - \alpha_{Lit} - \alpha_{Mit}) \Delta F_{Kit} + \alpha_{Lit} \Delta F_{Lit} + \alpha_{Mit} \Delta F_{Mit} - \Delta p_{it} + \Delta e_{it} \\ &= (\xi_{it} - \mu_{it}) \Delta e_{it} - \mu_{it}(\Delta p_{it} - \Delta F_{Kit}) \end{aligned} \quad (\text{B.3})$$

where F_{Kit} denotes the price of capital employed in the production function. The innovation of Roeger (1995) comes from using the dual Solow residual (SRP_{it}) to substitute for a change

²⁸Roeger (1995) shows that the change in the marginal cost (Δc_{it}) is a weighted average of the changes in input prices (F_{Iit}) with respect to their relative cost shares in the firm's cost function (ϕ_{Iit}), accounting for the change in technology (e_{it}), i.e. $\Delta c_{it} = \phi_{Iit}\Delta F_{Iit} - \Delta e_{it}$.

in productivity efficiency of a firm i at time t denoted by $\Delta\epsilon_{it}$ in (B.2). The advantage is that this method does not require instruments, which are large unavailable at the firm-level (but at aggregate level do not make sense due to little cross-firm variation). Subtracting the dual Solow residual from the primal Solow residual with Lerner index λ_{it} is derived in the following manner:

$$\begin{aligned} (\Delta q_{it} + \Delta p_{it}) - (\Delta k_{it} + \Delta F_{Kit}) &= \frac{1}{\mu_{it}} [(\Delta q_{it} + \Delta p_{it}) - \alpha_{Lit}(\Delta l_{it} + \Delta F_{Lit}) \\ &\quad - \alpha_{Mit}(\Delta m_{it} + \Delta F_{Mit}) - (\xi_{it} - \alpha_{Lit} - \alpha_{Mit})(\Delta k_{it} + \Delta F_{Kit})] \\ &\quad + \mu_{it} [(\Delta q_{it} + \Delta p_{it}) - (\Delta k_{it} + \Delta F_{Kit})] - [(\Delta q_{it} + \Delta p_{it}) \\ &\quad + (\xi_{it} - \alpha_{Lit} - \alpha_{Mit})(\Delta k_{it} + \Delta F_{Kit})] = \alpha_{Lit}(\Delta l_{it} + \Delta F_{Lit}) + \alpha_{Mit}(\Delta m_{it} + \Delta F_{Mit}) \\ &\quad (\Delta q_{it} + \Delta p_{it}) - [(\xi_{it} - \alpha_{Lit} - \alpha_{Mit})(\Delta k_{it} + \Delta F_{Kit}) + \alpha_{Lit}(\Delta l_{it} + \Delta F_{Lit}) \\ &\quad + \alpha_{Mit}(\Delta m_{it} + \Delta F_{Mit})] = \mu_{it} [(\Delta q_{it} + \Delta p_{it}) - (\Delta k_{it} + \Delta F_{Kit})] \end{aligned}$$

where the share of inputs (I_{it}) in total revenues ($P_{it}Q_{it}$) are denoted by $\alpha_{Lit} = \frac{F_{Lit}I_{it}}{P_{it}Q_{it}}$ with the letters F and P representing input and output prices. To obtain a price-cost margin term $\mu_{it} = \frac{P_{it} - c_{it}}{c_{it}}$, which can be directly estimated, one has to subtract the price-based residual SRP_{it} from the output-based residual SR_{it} as:

$$(\Delta q_{it} + \Delta p_{it}) - \sum_I \alpha_{Lit} \Delta F_{Lit} = \mu_{it} [(\Delta q_{it} + \Delta p_{it}) - (\Delta k_{it} + \Delta F_{Kit})] \quad (\text{B.4})$$

10 Annex C: The Variable Capital Model

Roeger and Warzynski (2004) point out that electricity firms could adopt more efficient ways to use the capital in generation of electricity. For example, firms could adopt more efficient techniques due to further deregulation of markets leading to increased competition. Technological improvements and further deregulation of European electricity markets could lead to reorganization of the capital stock, which would in turn reduce the use of fixed capital and free a fraction of variable capital for adjustments to changing market conditions. If this is the case, then the markup estimates should be controlled for the variable part of capital that responds to shifts in market conditions. If by contrast, the capital is considered as fully fixed, then the markup estimates will be biased upwards.

In what follows, I consider in line with Roeger and Warzynski (2004) that the total capital stock includes a fraction of capital that is adjusted to current demand and cost conditions. Within the log-linear homogeneous production function $Q_{it} = G(K_{it}, L_{it}, M_{it})E_{it}$, consider now that the capital stock $K_{it} = K_{it}^v + K_{it}^f$ includes both fixed capital K_{it}^f and variable capital input K_{it}^v . However, the share of variable capital is not directly observed in the data, hence Roeger and Warzynski (2004) propose a model that estimates the share of fixed capital in the production function. The model builds upon the Roeger (1995) approach with the markup term included in the TFP growth, but in addition exploits the bias in the TFP measurement proportional to the share of fixed capital. Similar to the Roeger (1995) model, define first the output-based and price-based Solow residuals, respectively SR_{it}^s and SRP_{it}^s , as:

$$SR_{it}^s = \Delta q_{it} - (\alpha_{Kit}^s \Delta k_{it} + \alpha_{Lit}^s \Delta l_{it} + \alpha_{Mit}^s \Delta m_{it}) + \Delta e_{it} \quad (\text{C.1})$$

$$SRP_{it}^s = \alpha_{Kit}^s \Delta F_{Kit} + \alpha_{Lit}^s \Delta F_{Lit} + \alpha_{Mit}^s \Delta F_{Mit} - \Delta p_{it} - \Delta e_{it} \quad (\text{C.2})$$

where the fractions of input costs in total costs ($F_{Lit}I_{it}$) are denoted by $\alpha_{Kit}^s = \frac{F_{Kit}K_{it}}{F_{Lit}I_{it}}$, $\alpha_{Lit}^s = \frac{F_{Lit}L_{it}}{F_{Lit}I_{it}}$ and $\alpha_{Mit}^s = \frac{F_{Mit}M_{it}}{F_{Lit}I_{it}}$ with the letter F denoting input prices and I_{it} total inputs. The contribution of factors and their prices to output and output prices should be weighted with their respective shares in variable costs, however the variable costs are not directly observed in the data. Following Roeger and Warzynski (2004), I first identify the measure of variable capital

and derive the model where the estimate of price-markup is controlled for the presence of variable capital.

10.1 Definition of Variable Capital

Within the log-linear production function $Q_{it} = G(K_{it}^s, L_{it}, M_{it})E_{it}$, consider that the degree of variable capital $0 \leq s_{it} < 1$ within the capital stock K_{it} is defined as:

$$s_{it} = \frac{K_{it}^v}{K_{it}} = \frac{K_{it}^v}{K_{it}^v + K_{it}^f} \quad (\text{C.3})$$

Assume that production function is a type of Leontief production function with production inputs N_{it} and K_{it}^v used in fixed proportions, so that $N_{it} = \frac{\alpha_{Lit}}{\alpha_{Kit}} K_{it}^v$:

$$Q_{it}^s = \min(\alpha_{Lit}L_{it}, \alpha_{Kit}K_{it}^v) - K_{it}^f \quad (\text{C.4})$$

The fractions of variable s_{it} and fixed capital $(1 - s_{it})$ are not directly observed in the data. Roeger and Warzynski (2004) show that the share of variable capital s_{it} varies with the firm size and economic activity and suggest to use measured labor productivity as its proxy. I adopt their assumption that both labor productivity and the variable capital share are increasing functions of output and thus labor productivity can be used as a proxy for variable capital share s_{it} . To clarify this relationship, define labor productivity as $x_{it} = \frac{Q_{it}^s}{N_{it}}$ using the above production function Q_{it}^s and derive the relationship between the growth rate of variable capital Δk_{it}^v and labor productivity $x_{it}(s_{it})$ using the observed information on total capital stock K_{it} , as:

$$\begin{aligned} x_{it} &= \alpha_{Lit} - \frac{K_{it}^f}{L_{it}} = \alpha_{Lit} - \frac{\alpha_{Lit}K_{it}^f}{\alpha_{Kit}K_{it}^v} \\ &= \alpha_{Lit} + \frac{\alpha_{Lit}}{\alpha_{Kit}} \left(\frac{s_{it} - 1}{s_{it}} \right) \quad , \quad \text{where} \quad \frac{K_{it}^f}{K_{it}^v} = \frac{1}{s_{it}} - 1 \end{aligned}$$

In the final step, differentiate $K_{it}^v = s_{it}K_{it}$, which leads to:

$$\begin{aligned} \frac{dK_{it}^v}{dt} &= \frac{ds_{it}}{dx_{it}} \frac{dx_{it}}{dt} K_{it} + s_{it} \frac{dK_{it}}{dt} \\ \frac{dK_{it}^v}{dt} / K_{it}^v &= \frac{ds_{it}}{dx_{it}} \frac{dx_{it}}{dt} \frac{K_{it}}{K_{it}^v} + s_{it} \frac{dK_{it}}{dt} \\ \Delta k_{it}^v &= \frac{ds_{it}}{dx_{it}} \frac{dx_{it}}{dt} \frac{1}{s_{it}} + \Delta k_{it} \\ \Delta k_{it}^v &= \frac{ds_{it}}{dx_{it}} \frac{dx_{it}}{s_{it}} \frac{dx_{it}}{dt} / x_{it} + \Delta k_{it} \\ \Delta k_{it}^v &= \varepsilon_{sx} \Delta x_{it} + \Delta k_{it} \quad (\text{C.5}) \end{aligned}$$

The variable capital is not directly observed in the data and Roeger and Warzynski (2004) suggest to express its growth rate in terms of measured labor productivity growth, Δx_{it} , and observable capital input, Δk_{it} . The growth rate of variable capital input is: The growth rate of variable capital Δk_{it}^v in (C.5), where Δk_{it}^v is proportional to growth of total capital growth Δk_{it} and labor productivity growth Δx_{it} weighted by the elasticity of the variable capital share with respect to labor productivity. I use this expression further in the analysis to derive the variable-cost based Solow residuals, specified as:

$$\Delta q_{it} = \frac{F_{Kit}K_{it}}{C_{it}^v} \Delta k_{it}^v + \frac{F_{Lit}L_{it}}{C_{it}^v} \Delta l_{it} + \frac{F_{Mit}M_{it}}{C_{it}^v} \Delta m_{it} + \Delta e_{it} \quad (C.6)$$

$$\Delta p_{it} = \frac{F_{Kit}K_{it}}{C_{it}^v} \Delta F_{Kit} + \frac{F_{Lit}L_{it}}{C_{it}^v} \Delta F_{Lit} + \frac{F_{Mit}M_{it}}{C_{it}^v} \Delta F_{Mit} - \Delta e_{it} \quad (C.7)$$

where the shares of input costs in total costs, $C_{it} = F_{Iit}I_{it}$, are denoted by $\alpha_{Kit}^s = \frac{F_{Kit}K_{it}}{F_{Iit}I_{it}}$, $\alpha_{Lit}^s = \frac{F_{Lit}L_{it}}{F_{Iit}I_{it}}$ and $\alpha_{Mit}^s = \frac{F_{Mit}M_{it}}{F_{Iit}I_{it}}$ with the letter F_{it} denoting input prices and I_{it} total inputs.

10.2 Identification of Variable Capital

The variable capital K^v is not directly observable. Consider the function of the firm variable costs, C_{it}^v , specified as:

$$C_{it}^v = C_{it} - C_{it}^f = C_{it} - (1 - s_{it})F_{Kit}K_{it} \quad (C.8)$$

$$\frac{C_{it}^v}{C_{it}} = [1 - (1 - s_{it})\frac{F_{Kit}K_{it}}{C_{it}}] \quad (C.9)$$

The expression (C.9) is then further used to derive the primal Solow residual weighted by the input shares in total costs in the following manner:

$$\frac{F_{Kit}K_{it}^v}{C_{it}} \Delta k_{it}^v = \frac{F_{Kit}K_{it}^v + (F_{Kit}K_{it} - F_{Kit}K_{it})}{C_{it}} \Delta k_{it}^v$$

; where $K_{it}^v = s_{it}K_{it}$

$$= \frac{F_{Kit}K_{it}}{C_{it}} \Delta k_{it}^v + \frac{F_{Kit}(K_{it}^v - K_{it})}{C_{it}} \Delta k_{it}^v$$

$$= \frac{F_{Kit}K_{it}}{C_{it}} \Delta k_{it}^v + \frac{F_{Kit}K_{it}(s_{it} - 1)}{C_{it}} \Delta k_{it}^v$$

$$= \frac{F_{Kit}K_{it}}{C_{it}} \Delta k_{it}^v - (1 - s_{it})\frac{F_{Kit}K_{it}}{C_{it}} \Delta k_{it}^v$$

$$\Delta k_{it}^v = \varepsilon_{sx}\Delta x_{it} + \Delta k_{it}$$

$$= \frac{F_{Kit}K_{it}}{C_{it}}(\varepsilon_{sx}\Delta x_{it} + \Delta k_{it}) - (1 - s_{it})\frac{F_{Kit}K_{it}}{C_{it}}(\varepsilon_{sx}\Delta x_{it} + \Delta k_{it})$$

$$[1 - (1 - s_{it})\frac{F_{Kit}K_{it}}{C_{it}}] \Delta q_{it} = \frac{F_{Kit}K_{it}^v(1 + s_{it} - s_{it})}{C_{it}}(\varepsilon_{sx}\Delta x_{it} + \Delta k_{it})$$

$$+ \alpha_{Lit}^s \Delta l_{it} + \alpha_{Mit}^s \Delta m_{it} + \frac{C_{it}^v}{C_{it}} \Delta e_{it}$$

$$\begin{aligned}
& \Delta q_{it} - \alpha_{Kit}^s \Delta k_{it} - \alpha_{Lit}^s \Delta l_{it} - \alpha_{Mit}^s \Delta m_{it} \\
&= (1 - s_{it}) \alpha_{Kit}^s \Delta q_{it} + \frac{F_{Kit}(K_{it}^v - K_{it})}{C_{it}} \Delta k_{it} + \frac{C_{it}^v}{C_{it}} \Delta e_{it} \\
&= (1 - s_{it})(\Delta q_{it} - \Delta k_{it}) + \alpha_{Kit}^s \varepsilon \Delta x_{it} - (1 - s_{it}) \alpha_{Kit}^s \varepsilon_{sx} \Delta x_{it} + \frac{C_{it}^v}{C_{it}} \Delta e_{it} \\
& \quad SRQ_{it}^s = (1 - s_{it})(\Delta q_{it} - \Delta k_{it}) + s_{it} \alpha_{Kit}^s \varepsilon_{sx} \Delta x_{it} + \frac{C_{it}^v}{C_{it}} \Delta e_{it} \tag{C.10}
\end{aligned}$$

Equation (C.10) is directly comparable to the result of Roeger and Warzynski (2004). A similar logic is used to retrieve the price-based Solow residual weighted by the input shares in total costs, that is:

$$\begin{aligned}
& \Delta p_{it} - \alpha_{Kit}^s \Delta F_{Kit} - \alpha_{Lit}^s \Delta F_{Lit} - \alpha_{Mit}^s \Delta F_{Mit} = (s_{it} - 1)(\Delta p_{it} - \Delta F_{Kit}) \alpha_{Kit}^s + \frac{C_{it}^v}{C_{it}} \Delta e_{it} \\
& \quad SRP_{it}^s = (s_{it} - 1)(\Delta p_{it} - \Delta F_{Kit}) \alpha_{Kit}^s + \frac{C_{it}^v}{C_{it}} \Delta e_{it} \tag{C.11}
\end{aligned}$$

Subtraction of the primal Solow residual (C.10) from the price-based Solow residual (C.11) gives the expression:

$$SRQ_{it}^s - SRP_{it}^s = [1 - s_{it}] \alpha_{Kit}^s [(\Delta q_{it} + \Delta p_{it}) - (\Delta k_{it} + \Delta r_{it})] + s_{it} \alpha_{Kit}^s \varepsilon_{sx} \Delta x_{it} \tag{C.12}$$

The testable econometric model with variable capital costs can be expressed as $\Delta Y_{it}^s = \sigma_{it} \Delta X_{it}^s$. The left-hand side variable (ΔY_{it}^s) represents the growth rate in revenues per value of input costs weighted by their shares in total costs and the right-hand side explanatory variable (ΔX_{it}^s) represents the growth rate in revenues per capital weighted by the share of capital in total costs of a firm i at time t . In the next step, the relationship between labour productivity x_{it} and the share of variable capital s_{it} is described by a nonlinear logistic function defined by Roeger and Warzynski (2004) as:

$$s_{it} = [1 + \exp(s_o + s_1 x_{it} + u_{it})]^{-1} ; \text{ where } u_{it} \text{ is an error term} \tag{C.13}$$