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The Trade-off Between Static and Dynamic Efficiency in Electricity Markets - A Cross Country Study

Working Paper

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Abstract:

This paper is the first to explicitly test for the presence of a trade-off between static and dynamic efficiency in a regulated industry, the electricity industry. We show for 16 European countries over the period 1998-2007 that higher electricity end-user prices in a country subsequently lead to higher investments in the capital stock, i.e. in generation, distribution and transmission assets. Moreover, there is a trade-off between vertical economies and competition. Ownership unbundling and forced access to the incumbent transmission grid increase competition but come at the cost of lost vertical economies. Generally, we find that regulation that affect only the *market* like the establishment of a wholesale market or free choice of suppliers increase investment activity via spurring competition. Regulation, however, that adversely affects the *incumbent* directly, like ownership unbundling, decreases aggregate investment spending.

Keywords: Static and dynamic efficiency, vertical economies, ownership unbundling, regulation, electricity, investments

JEL classification: L43, L52, L94

1. Introduction

The Sector Inquiry published on January 2007 highlighted a lack of competition in European energy markets, and although legal and functional unbundling are accepted in their positive impact, it was concluded that these regulatory reforms are not sufficient to contribute to certain energy political goals. In this context, further steps of unbundling such as ownership unbundling, a deep ISO (independent system operator) or an ITO (independent transmission operator) are seen as appropriate to stimulate competition, trigger investments, and assess the evolution towards an integrated European energy market. Hence, the European Commission passed a third legislative package in September 2007. In its centre lies the vertical unbundling of transmission companies and long-distance transport in the electricity as well as the gas sector. However, up to now, no unambiguous evidence of positive effects of unbundling on prices or market concentration exists, as mentioned in, for example Florio (2007), nor is there evidence on its effects on investment incentives in energy markets, beside Nardi (2010).

Theory not only indicates that the unambiguously positive view of ownership unbundling by the European Commission is not warranted, there are much wider, inherent trade-offs between static and dynamic efficiency, and between vertical synergies and competition. Higher mark-up industries are likely to attract more new investments than low mark-up industries, provided there is a sufficiently high level of competition. Thus, higher prices - while inducing allocative and static inefficiencies - increase the attractiveness to invest and therefore dynamic efficiency.[1] Likewise, there is a well established literature on the benefits of vertical integration, ranging from the avoidance of double marginalization to the internalization of spillovers and better coordination, to name only a few. Forced access or break up of companies - while guaranteeing equal treatment of firms – are not for free and come at the costs of coordination failures and other diseconomies of vertical disintegration.[2]

This paper tries to fill the lack of evidence on the effects of regulation on investments. We are the first to explicitly test for the effects of *ownership* unbundling of the transmission grid as well as final consumer *prices* on investments, and corroborate the inherent trade-offs present in large sunk cost network industries. We estimate dynamic panel regression models for the electricity industry in 16 European countries over the period 1998-2007, and find that ownership unbundling reduces investments in the electricity industry. We also estimate an investment reducing effect of third party access to the electricity transmission grid. Moreover,

[1] This is, of course, a variation of the trade-offs analyzed in the patent literature, see e.g. Nordhaus (1969).

[2] In a recent survey, Meyer (2010) outlines the main effects of (ownership) unbundling on efficiency. Depending on the unbundling scenario (generation; distribution and retail; transmission; and distribution unbundling), coordination failures and market risk effects lead to efficiency losses of up to 17% for the broken-up companies.

there is a general trade-off between static and dynamic efficiency. Higher electricity end-user prices induce higher investments in the sector. We also find that introducing competition via *market* based measures – such as establishing a wholesale market for electricity or abolishing minimum consumption thresholds for switching to alternative suppliers – increases investment spending. These measures increase competition and investment spending without unduly destroying the incentives of the incumbent to invest.

Methodologically, we care mostly about two problems. First, there are inherent endogeneity problems of investment determinants. "Regulation" may well be determined by investments, the same may be true by "prices". Therefore, we do not only apply consistent estimation techniques such as GMM but explicitly test for Granger causal relationships among the main variables of interest, and accordingly estimate instrumented regressions. Second, a general problem is that it is hardly possible to disentangle the effects of the coincident timing of different types of regulation. Pollitt (2008) e.g. says: "…ownership unbundling of transmission networks may occur at the same time as privatisation, the restructuring of generation or production markets, the introduction of incentive regulation etc." We try to disentangle these potentially coincident relations by utilizing the time series variation of the main variables of interest in our panel, and lag them up to two years in our regressions.

The remainder of this paper is organized as follows. Section 2 gives a short literature overview over the existing theoretical models and empirical evidence on unbundling. Section 3 develops our main hypotheses. Section 4 describes our data set, section 5 presents the main results, and section 6 contains robustness checks. Finally, section 7 concludes.

2. Literature Survey

Several theoretical articles analyze the impact of ownership unbundling[3] on consumer prices and investments. Bolle and Breitmoser (2006) show that ownership unbundling leads to a more effective regulation. They, however, highlight that it causes the problem of double marginalization, which implies price increases in the long run. Overall, they find that the negative effects of double marginalization outweigh the positive effects in such a way that legal unbundling becomes preferred to ownership unbundling. Cremer et al. (2006) also show that ownership unbundling is more detrimental to social welfare than legal unbundling. They

[3] Ownership unbundling requires the system operator of the networks to be fully unbundled from the rest of the former integrated system, which means that ownership and control of the power lines have to be fully separated.

ascribe this effect to the higher incentives for investments under legal unbundling, since under this regime other parts of the company can still benefit from investments done from the formerly vertical integrated company, which is not the case under ownership unbundling. In a similar approach, Höffler and Kranz (2011) confirm the previous findings and show that the desirable properties of legal unbundling with special regard to social welfare and investment incentives can only be achieved if there is a strong, effective and independent regulation. For a comprehensive survey on the effects of unbundling in the electricity sector, see Meyer (2010). He concludes that there are significant vertical synergies that are lost particularly if generation unbundling is introduced (separation of generation from the two network stages transmission and distribution). According to Meyer (2010), the ISO option, where ownership remains unchanged, while operating and investment decisions are handed over to a company without commercial supply interests, would be the "golden mean".

In contrast, Pollitt (2008) criticizes Bolle and Breitmoser (2006), and Cremer et al. (2006) because of their underlying assumptions. He reports that reverse results can be expected if more realistic assumptions are incorporated. For the former study he states that their model should take into account anti-competitive information advantages of legal unbundling for the rest of the integrated firm, while the latter does not consider the competition enhancing effect of ownership unbundling as well as the fact that double marginalization assumes one-part tariffs, which is usually not the case for the electricity sector. Brunekreeft (2008), and Brunekreeft and Meyer (2008) analyze the possible effects of different types of unbundling in electricity markets on competition and cost evolution by means of a cost-benefit analysis. They deduce that ownership unbundling may not directly lead to expansion investments, but if capacity becomes scarce, it may support investment decisions if the considered time period covers about 20 years.

Up to now no unambiguous empirical evidence of positive effects of ownership unbundling on prices or market concentration exists, as mentioned in, for example Florio (2007), nor is there evidence on its effects on investment incentives in energy markets, beside Nardi (2010). Nevertheless, several studies cover the impact of different types of regulation or liberalization. Steiner (2001) is one of the first articles covering the effects of liberalization on consumer prices. She analyzes data from 19 OECD countries spanning a time period from 1986 to 1996. She finds that unbundling of generation and transmission facilities leads to increasing efficiency for the overall sector, however, the possible benefits are not necessarily shifted to private consumers via lower prices. No distinction between accounting separation and legal- or ownership unbundling is made.

Hattori and Tsutsui (2004), opposite to Steiner (2001), find that unbundling appears to increase prices. However, an explicit distinction of the different types of unbundling is again not made. Copenhagen Economics (2005) deals with the level of market opening in several network industries by means of a dynamic panel data model. They focus on the EU-15 countries from 1993 to 2003 and conclude that higher levels of unbundling (with ownership unbundling as the highest form) lead to price reductions and increasing efficiency. Moreover, they conclude that unbundling of the transmission grid is the most important element of market opening. However, for the gas sector they cannot confirm this negative effect of unbundling on prices.

More recently, Fiorio and Florio (2009) show for the electricity industry that vertical integration leads to higher final consumer prices, and using a standard probit model, they conclude that consumers are less satisfied if firms are integrated. In line with earlier studies, their results for the gas industry differ substantially. Herein, prices and vertical integration are uncorrelated, and consumers are more satisfied with higher levels of integration. Similar studies dealing exclusively with the gas industry are Brau et al. (2010) and Growitsch and Stronzik (2009). The latter paper explicitly accounts for ownership unbundling, but the authors do not find a significant effect of ownership unbundling on prices.

Most of the previously mentioned articles focus on the impact of unbundling on prices or efficiency, but neglect the effects on investments. The most important empirical study in this context is by Alesina et al. (2005), who analyze different regulatory reform processes in seven network industries in 21 OECD countries covering the time period 1975 to 1998. The authors show that regulatory reform of product markets has a positive effect on investments. Analyzing the gas and electricity sector jointly, they come to the conclusion that investments increase according to stricter levels of unbundling. However, they do not differentiate between ownership and legal unbundling.

Nardi (2010) undermines these findings. He analyzes the impact of ownership unbundling on grid investments and quality. Although he finds higher grid investments in the network, he further shows that a substantial lack of quality emerges that confirms the resulting diseconomies of coordination when separating ownership and control of different company parts. According to the author his results should be seen as first findings, since only qualitative investment data is available and therefore no multivariate regression analysis can take place. Nevertheless, to our knowledge this is the only paper that explicitly analyzes the impact of ownership unbundling on (grid) investments, in spite of the difficult data situation.

3. Hypotheses on the determinants of investments

There is a general ambiguity of the effects of competition on investments, and since regulation intrinsically affects the competitive process, there is an ambiguous relation between regulation and investments. In what follows, we detail the likely effects of three categories of investment determinants, (1) investment opportunities and competitive effects as measured by prices in the market; (2) regulation, and (3) ownership structure.

3.1. The effects of prices on investments

Ceteris paribus, a higher price implies better investment opportunities and therefore larger investments, since rents are higher from expanding the capital stock in a high mark-up industry than in a low mark-up industry. This effect can be called "Schumpeterian", and it is the underlying force in Dixit and Stiglitz (1977) type of models of competition and innovation. One of the novelties of this paper lies in the explicit introduction of a measure for "investment opportunities" in the investment model. Thus, we are able to explicitly show the *trade-off between static and dynamic efficiency*.

However, there are at least two objections to this "naive" line of reasoning. First, a larger mark-up does not need to only capture the efficiency of the firm and thus its investment opportunities, it could also capture its monopoly rents. If so, the effects of larger prices on investment incentives depend in an intricate way on the threat of losing these rents, i.e. on the firm relevant counterfactual of not investing. When there is no danger of losing existing rents, so that the firm is essentially an uncontested monopoly, the counterfactual of not investing is the status quo, i.e. no other firm can compete existing rents away. This gives rise to the Arrow (1962) "replacement effect", implying a low propensity to invest in new products or processes. Larger prices then are just an indication of a low threat of entry, and the monopoly should invest very little, since new profits from investments just replace old profits.

If there is a reasonably high threat that the counterfactual of not investing is that another firm will invest and capture the accruing rents, the Aghion et al. (2005) "escape competition" effect should lead to a positive relation between mark-ups and investments. Larger mark-ups imply more to loose from not investing if there is competition for these rents. Note, that although the direction of effects is the same compared to the situation when prices measure investment opportunities, the interpretation slightly differs. If prices only measure investment opportunities, the firm will invest more – independent of the competitive situation. If prices measure rents, the firm will invest more only when there is a reasonably high threat to loose these rents if not investing.

Second, high prices and investments may be endogenous. Investments, at least the depreciation part of it, are – when accepted by the regulator – part of the regulatory base, and thus increase energy prices by definition if regulation is "cost plus". Moreover, investments determine prices, if the competitive position of the firm is altered by this investments (reverse causality). We econometrically tackle these problems of causality below.

3.2. The effects of (access) regulation on investments

Regulation and in particular access regulation should increase the ease with which firms can enter the market and compete with the incumbent. Logically, regulation can be decomposed into (1) regulation affecting only the *market* directly (e.g. the existence respective non-existence of a liberalized wholesale market or of a minimum consumption threshold of consumer switching their supplier) and (2) regulation affecting also the *incumbent* directly (e.g. third party access or whether the incumbent is only legally unbundled or ownership unbundled).

Again, the effects of regulation on investments are ex ante ambiguous and may differ between incumbents and entrants. Stricter (access) regulation reduces the incentives of the incumbent to invest, since (i) it lowers the Net Present Value (NPV) of incumbent's investments because cost based access reduces rents (Valletti (2003) or Pindyck (2007)); (ii) it shifts risk from entrants to incumbents because entrants enjoy a risk-free option to lease infrastructure and exploit the regulatory arbitrage between wholesale and retail prices when demand uncertainty is resolved., and (iii) it increases overall risk of the incumbent and therefore its cost of capital, see Jorde et al. (2000). In addition, (iv) ownership unbundling of the activities of the incumbent on different stages of the production process (e.g. generation and grids) can have detrimental effects. There are several reasons for that. First, double marginalization problems are introduced by ownership unbundling, which decrease the overall rents that can be earned in this market and therefore investments. Second, spillovers and network externalities between up- and downstream operations can no longer be internalized by the same firm. Third, a coordination failure between infrastructure investments and generation assets may result if the decision making entities differ. Finally, a separated grid operator is a much smaller firm than the vertically integrated incumbent, and due to size and financial resources effects may invest less.

The positive effects of (access) regulation on investments are: (1) A vertically integrated incumbent may not raise retail competitor's costs if the competitor is more efficient, see for instance Rey and Tirole (2007), and Sibley and Weismann (1998). Moreover, Foros (2004) and Kotakorpi (2006) show that service-based competition, if it increases variety and innovation and, concomitantly, demand, might encourage investments by incumbents. An example for the electricity sector is the introduction of smart grids, where substantial investments have to be made in the up-coming years. (2) The so-called "investment ladder" theory Cave and Vogelsang (2003); Cave (2006) implies that low access fees enable entrants to build up an installed base and learn about demand and cost conditions and they will eventually roll out their own networks. (3) Finally, access regulation can precipitate a "race" to provide infrastructure increasing investments by incumbents and entrants Valletti (2003).

In addition to these positive effects of market access regulation, regulating the incumbent directly may further spur competition in the market and thus investments. In case of ownerhsip unbundling, it reduces the scope for discrimination against entrants, since the newly created grid operator – like a two sided-market platform – has an incentive to spur competition upstream (e.g. generation) and downstream (e.g. retail) and treat all firms equally. This increases investments by entrants, but could also increase investments by incumbents depending on where on the inverted U-shape the industry is positioned.

3.3. The effects of ownership structure on investments

The ownership structure in the electricity sector may affect investments in two ways, first via efficiency and second via incentive or objective effects. Unambiguously, more efficient firms should invest more, either because they serve a larger market including also low willingness-to-pay-consumers (demand effect) or they obtain a larger market share (competitive effect). If public ownership implies X-inefficiency, therefore, we should see less investments in predominantly state-controlled energy sectors. On the other hand, the state and state-controlled firms may have objectives or incentives that differ from privately-controlled firms, and these objectives may include the build up of a good and secure infrastructure for electricity. Since budget constraints of state-controlled may be softer than for privately-controlled firms, they may be able to invest more.

4. Data

Table 1 presents an overview and definitions of the variables used in the subsequent regression analysis.[4] Investments, I, are gross investments in tangible goods in the overall electricity industry, and thus include investments in generation, distribution and transmission assets. Capital stock data is not readily available, thus we use the perpetual inventory method, see e.g. Fazzari et al. (1987) and Salinger and Summers (1983). Capital stock, K, is calculated according to the formula: $K_t = K_{t-1} - \delta K_{t-1} + I_t$, where K_t is the capital stock in period t, δ is the depreciation rate and I_t equals investments. Due to the long-term nature of investments in the electricity sector we assume a depreciation rate of five percent, see e.g. Alesina et al. (2005). We exclude the first three years of every country-panel to arrive at the first K_t used in the regressions.[5]

The variables of main interest are final consumer prices, *P*, the four regulatory variables, ownership unbundling, *OU*, third party access to the transmission grid, *TPA*, liberalized wholesale market, *LWM*, minimum consumption threshold, *MCT*, and the public ownership variable, *PO*. Electricity end-user prices for households are purchasing power parity and taxes corrected, and are measured in USD per kWh. The regulatory variables are coded such, that larger values indicate more stringent regulation. Thus, we code *OU* as 1 if there is ownership unbundling of the transmission grid, and 0 if there is no OU. *OU* is based on several publications of the EU Commission, namely different benchmarking reports and various reports on progress in creating the internal gas and electricity market. If there has been any misleading or conflicting evidence, the corresponding national authority has been contacted. *TPA* is 2, if there is a regulated TPA, 1 if third party access is negotiated, and *TPA* = 0, if there is no TPA. The existence or non-existence of a liberalized wholesale market for electricity is coded as 1 = LWM, and 0 = no LWM. If *MCT* = 5, there is no minimum consumption threshold for consumers to be allowed to choose their electricity supplier, and if *MCT* = 0 consumers have no choice of the supplier. *MCT* takes on values in between depending on the amount of electricity that must be consumed annually. Thus, *MCT* = 4, if there exists a threshold but this threshold is smaller than 250 gigawatts (GW), *MCT* = 3, if consumption must be between 250 and 500 GW, *MCT* = 2, if consumption must be between 500 and 1000 GW, *MCT* = 1, if annual consumption must be more than 1000 GW. Finally, we

[4] Our sample is an unbalanced panel which contains data for 16 European countries over the period 1998-2007.

[5] We also tried four and five years, but since results are very similar we only report the results on leaving out the first three years of investment. This also holds true for the special case of Spain, where there was very little investments in the first three years (1995-97) of our sample, possibly due to the starting regulatory reform process from 1997 onwards.

measure the ownership structure of the largest companies in the generation, transmission, distribution and supply segments of the electricity industry by *PO*, taking on the value 0, if firms are private, 1 if they are mostly private, 2 if they are mixed, 3 if they are mostly public, and 4 if they are public.

Table 2 presents evidence on investments and prices as well as on the regulatory variables and public ownership. Table 2a shows that average investment rates vary between 4% (Austria, Czech Republic, Germany, Slovak Republic) and 30% for Spain. The average *I/K* is 8.8%**.** Electricity is cheapest in Norway and Sweden (average of 5 USD cents per kWh) and most expensive in Portugal (20 cents). The average kWh costs around 12.5 cents.

For our reporting period five countries (Austria, Belgium, France, Germany and Hungary) do not have ownership unbundling at all, although of course there is legal unbundling in all countries (see Table 2b). At the other extreme, Finland and Sweden were the first to ownership-unbundle the transmission grid from generation. Finally, there is a group of countries switching from legal unbundling to ownership unbundling during our sample period (Czech Republic, Denmark, Italy, Norway, Poland, Portugal, Slovak Republic, Spain, and the UK. Most countries introduced regulated third party access in the years 1999 or 2000, only Hungary (2002) and Germany (2006) came later (Sweden, Finland and the UK introduced regulated third party access already in 1995/96). With the exceptions of Belgium, Poland and the Slovak Republic, all countries either had already a liberalized wholesale market before the start of our sample period or introduced it during the sample period. Minimum consumption thresholds for freely choosing one's electricity supplier were either phased out during the sample period or were already abolished before 1998 in all countries. Rather diverse ownership structures can be observed across countries. While Germany, the UK and Belgium have either private or mostly private electricity sectors, the state still plays a major role in the other countries.

5. Econometric modeling

The most important determinant of investments should be the expected future profitability of investments. This would accompany the fundamental forward looking nature of investments: without capital market failures the firm should maximize its present value, given a set of capitalization rates of expected future returns and given a set of initial conditions (e.g. the existing stock of capital). If the firm maximizes the discounted flow of profits over an infinite horizon absent delivery lags, adjustment costs, and vintage effects, capital depreciates at a geometric rate and assuming a constant elasticity of substitution (CES) production function with σ the constant elasticity of substitution between capital and variable inputs, the relationship between the desired (optimal) capital stock K^*, the level of output Y, and the cost of capital c can be written as

$$K_t^* = \alpha c_t^{-\sigma} Y_t \tag{1}$$

where c is a function of the purchase price of new capital relative to the price of output, see Chirinko (1993) and Caballero et al. (1995). Taking logs of (1) and denoting logarithms with lower case letters, we get

$$k_t^* = a - \sigma c_t + y_t \tag{2}$$

In the absence of adjustment costs, k_t^* would be the optimal capital stock for a profit maximizing firm with a constant returns to scale CES production function. Adjustment processes may be complex, and one simple way to arrive at a tractable model and account for adjustment costs is to nest (2) within an autoregressive-distributed lag model, for example an autoregressive-distributed lag ADL (1,1) model of the form

$$k_t = \alpha_0 + \alpha_1 k_{t-1} + \beta_0 y_t + \beta_1 y_{t-1} - \varphi_0 c_t - \varphi_1 c_{t-1} + u_t \tag{3}$$

Further assuming that the change in the capital stock can be described by a simple partial adjustment process of the form

$$\Delta k_t = \theta(k_t^* - k_{t-1}) + \varepsilon_t \tag{4}$$

where some constant fraction θ of the gap between the actual and the desired levels of the capital stock is closed in each period, we get the error correction specification as

$$\begin{aligned}\Delta k_t = {} & \theta\alpha_0 - \theta(1-\alpha_1)\Delta k_{t-1} + \theta\beta_0\Delta y_t + \theta(\beta_0 + \beta_1)\Delta y_{t-1} - \theta\varphi_0 c_t - \theta\varphi_0 c_{t-2} \\ & -\theta(1-\theta\alpha_1)k_{t-2} + \theta[\beta_1 - \beta_0(1-\theta\alpha_1)]y_{t-2} + \psi_t\end{aligned} \tag{5}$$

Assuming that the variation in the user cost of capital can be controlled for by including additive year-specific effects (λ_t), the real interest rate r, country-specific effects (

η_i), that electricity prices p inversely capture c, and finally using the approximation that $\Delta k_t \approx I_{it} / K_{i,t-1} - \delta_i$,[6] we get the dynamic investment equation

$$\frac{I_{it}}{K_{i,t-1}} = \eta_i + \lambda_t + \rho \frac{I_{i,t-1}}{K_{i,t-2}} + \upsilon_0 p_{it} + \upsilon_1 p_{i,t-1} + \theta_0 \Delta y_t + \theta_1 \Delta y_{t-1} + \nu_0 k_{t-2} + \nu_1 y_{t-2} + \tau_0 r_t + \tau_1 r_{t-1} + \\ + regulation + ownership + \psi_{it} \qquad (6)$$

where we further include our variables measuring *regulation* and *ownership* structure, and with $\psi_t = \theta u_t + \varepsilon_t - \alpha_1 \varepsilon_{t-1}$. In the econometric estimation we lag all predermined explanatory variables by an additional period to reduce endogeneity problems. If adjustment costs to the desired capital stock are important in the electricity sector, we expect a positive and significant ρ. θ_1 and θ_2 measure accelerator effects, ν_0 and ν_1 error correction, i.e. a negative ν_0 or a positive ν_1 imply more future investments in case of the capital stock being below the desired level. Positive υ_0 and υ_1 imply a preponderance of positive effects of higher relative output prices. The effects of regulation and ownership structure on investments are ambiguous, and depend on the trade-off between vertical synergies and competition, and the amount of X-inefficiency versus the objectives of the state. We measure y by energy consumption.

6. Regression Results

Table 3a presents our main regression results, while Table 3b calculates short and long-run effects for the dynamic panel equations. The table compares country fixed effects estimates with GMM, the latter consistently estimating a dynamic panel.[7] This is done for a model specification with and without the error correction terms. The GMM model estimates the regression augmenting it by a lagged dependent variable using the difference GMM estimator. This estimator eliminates country fixed effects by first-differencing as well as controls for possible endogeneity of current explanatory variables. Endogenous variables lagged two or more periods will be valid instruments provided that there is no second-order autocorrelation in the first-differenced idiosyncratic error terms.[8] The Sargan test does not suggest rejection

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[6] δ_i is subsumed into the unobserved country-fixed effects.

[7] We also applied the LSDVC estimator from Bruno (2005) which is especially designed for dynamic unbalanced panel data models, but our main results remain unchanged and are available upon request.

[8] Due to the possible problem of too many instruments we restrict the maximum number of lags used as instruments at a maximum of three.

of the over-identifying restrictions at conventional levels. While there is evidence of first order serial correlation in the residuals, the AR(2) test statistic reveals absence of second order serial correlation in the first differenced errors. Our GMM estimates therefore use variables lagged by two or more periods as instruments. The Hausman tests indicate that coefficient estimates via fixed effects are not significantly different from GMM-DIFF estimates.

Four results stand out. First, lagged investments per capital stock have a positive effect on investment activity in a country's electricity market in the current year. Therefore, investments in the electricity sector are characterized by path dependency, presumably because adjustment costs are large in high sunk costs industries. This is also underlined by negative resp. positive error correction coefficients v_1 resp. v_2, implying adjustment to a new desired capital stock is gradual. These results are consistent with the findings of Alesina et al. (2005) for seven regulated sectors in OECD countries and Friederiszick et al. (2008), and Grajek and Röller (2009) for the telecom sector.

Second, we estimate a significant trade-off between static and dynamic efficiency. Table 3b indicates that the short and long-run effects of prices on investments with GMM-Diff are positive and significant. In the long run, an increase in prices by 10% increases the investment ratio by 5.7% (see GMM-Diff without ECM). This indicates that higher prices, while inducing static or allocative inefficiencies, increase the rents that can be earned from investments and trigger more investments, which presumably increase dynamic efficiency. Note that all our regressions include country and year effects controlling for unobserved country (such as cost variations across countries) and business cycle effects. Thus, the time series variation in prices within countries most likely captures variations in the Lerner indexes (mark-ups) over time, and thus rents to be earned from investments.

Third, ownership unbundling affects investment spending significantly negatively. Again looking at Table 3b, both short-run and long-run negative effects are sizeable and significant. Remembering the theoretical arguments from above, the negative double marginalization, coordination failure and non-internalization of spillover effects appear to outweigh any positive competitive effects. The second measure of direct *incumbent* regulation, third party access, also appears to reduce investments in the electricity sector, but less significantly. In contrast, stricter *market* based regulation appears to be beneficial to investments via spurring competition in the market. The presence of a liberalized wholesale market significantly increases investment spending in the GMM-Diff as well as fixed effects estimations without ECM. Although the sign estimates point to the same conclusion, *MCT* effects are not significant. Our results imply that increasing competition via market based instruments generally appear to increase also investments (and not only competition), consistent with the electricity industry still being located to the left of the maximum of the relation between competition and innovation (and investments), see Aghion et al. (2005). However, increasing competition via forcing the incumbent to provide cost based access or via ownership unbundling mainly entails negative effects on investments.[9]

Finally, most estimates on public ownership lead us to conclude that it is detrimental to investments, although the GMM-DIFF with ECM estimates indicate positive but insignificant effects. The X-inefficiency following from public ownership and control appears to outweigh any positive objective effects on investments.

6. Robustness

6.1. Different Counterfactuals

When analyzing the effects of ownership unbundling (or the other regulatory variables), one may criticize our approach in the foregoing section by including all countries in the regression, i.e. also those countries that already had OU before the start of the estimation period. Thus, the control group may be somewhat contaminated, since the estimates of the effects of the introduction of OU are relative to a mixture of countries before the introduction of OU, countries that never introduced OU, and countries that already had introduced OU before the start of the sample period. Table 4 sample-selects only those countries that switched from legal unbundling to ownership unbundling (CZ, DK, ITA, NOR, POL, POR, SK, SP, UK) during our estimation period (1998-2007), as well as those countries that did not introduce OU until the end of the sample period (AT, BE, FR, GER, and HU). Thus, the estimates of the effects of OU allow a before/after introduction of OU comparison relative to non-switching countries, i.e. a difference-in-difference comparison.

The table presents the short and long-run effects of the main variables of interest. All our results hold up, some are even more significant. Higher prices lead to higher investments, ownership unbundling and forced third party access decrease investment incentives, however, market based opening (LWM and MCT) increase investments. The effects of public ownership are more on the negative side.

[9] Note that this does not preclude positive static effects of these measures.

6.2. Granger Testing and Reverse Causality

While we have attempted to effectively use the data's panel structure (by controlling for fixed country and time specific effects and lagging our independent variables) in order to generate sound causal inferences, the reciprocal causation problem may still be evident in our econometric estimations. Namely, it could be that high investments in a country's electricity sector induce firms to set lower prices, since capacity is higher. It could also be that the regulatory variables are partly caused by high investments, e.g. the regulatory authority may be more confident to switch to ownership unbundling or stricter third party access if investments are high anyway. Causality would then also run from investments to our variables of interest. Accordingly, we test for causality amongst investments, prices, regulatory and ownership variables.

In testing for causality, we apply standard Granger causality tests Granger (1969). Namely, we use a standard joint test (e.g. χ^2-test) of exclusion restrictions to determine whether lagged X has significant linear predictive power regarding current Y. The null hypothesis that X does not strictly Granger cause Y is rejected if the coefficients on the lagged variables of X are jointly/significantly different from zero. Bidirectional causality (or, feedback) exists if Granger causality runs in both directions. In particular, we will consider two lags in order to test Granger causality. Since we must include lagged dependent variables in these Granger tests, estimation with OLS would be inconsistent in the presence of unobserved country-fixed effects. Therefore, we estimate our equations again with GMM.

Table 5 presents our estimation results for these tests of strict Granger causality from X to Y. The table presents the p-values for the Granger-$\chi^2(2)$ tests. While prices significantly help predict investments in the subsequent two years, investments are also significant predictors for prices. Thus, we cannot exclude partial bi-directiobnal causality between prices and investments. The same conclusions apply to MCT and PO.

Table 6 reports results on dynamic investment equations treating *prices* as endogenous (column 1), *prices, MCT and PO* as endogenous (column 2), and *all our variables* of interest as endogenous (column 3). We use lagged values of these variables as instruments. All our main results hold up, some become even clearer and more significant. Sargan tests as well as the tests for autocorrelation of order one and two are in line with our previous findings.

7. Conclusions

Estimating dynamic panel regression models for 16 European countries over the period 1998-2007, we test for the interrelations between investments, prices and regulation in a regulated network industry, the electricity industry. We find evidence for the presence of both kinds of trade-offs, the trade-off between static and dynamic efficiency, and the trade-off between vertical synergies and competition.

We come to a rather negative conclusion what concerns the dynamic effects of ownership unbundling of the transmission grid. Unbundling of ownership of the generation from the grid stages reduces the investment rate by about five percentage points. We also estimate an investment reducing effect of forced third party access to the transmission grid. Higher electricity end-user prices induce higher investments in the overall sector.

However, we do not argue that competition introduced via regulation per se reduces investments, but that the way competition is introduced has important consequences. Giving entrants directly access to the incumbent's network via cost based access charges or owner unbundling the incumbent's grid from other stages of the supply chain, introduce vertical diseconomies, non-internalization of network effects and coordination failures, such that the net effect on investments is negative, at least in electricity markets. Introducing competition via *market* based measures – such as establishing a wholesale market for electricity or abolishing minimum consumption thresholds for switching to alternative suppliers - increases investment spending. These measures increase competition and investment spending *without* unduly destroying the incentives to invest.

Theory indicates that there are inherent trade-offs in high sunk costs network industries. There is a trade-off between static and dynamic efficiency, and there is a trade-off between vertical synergies and competition. Higher prices induce static inefficiencies, but they induce firms to invest. Ownership unbundling prohibits discrimination among firms and may ameliorate allocative efficiency, but it destroys incentives to invest. Not surprisingly, we find that there is no free lunch in economics.

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Table 1: Variable Definitions

Variable	Variable description	Source
Investments, I	Gross investments in tangible goods in the overall electricity industry (i.e. investments in generation, distribution or transmission assets)	Eurostat
Capital stock, K	Since capital stock data is not directly available from the data base, we derive it indirectly from investments using the perpetual-inventory method	Eurostat
Final consumer prices, P	Electricity end-user prices for households in USD per kWh. Prices are purchasing power parity corrected and taxes are subtracted.	IEA
Ownership unbundling, OU	Ownership unbundling of the transmission grid (0 = no OU, 1 = OU)	EU documents
Third party access, TPA	Third party access to the electricity transmission grid (0 = no TPA, 1 = negotiated TPA, 2 = regulated TPA)	OECD International Regulation Database
Liberalized wholesale market, LWM	Existence of a liberalized wholesale market for electricity (0 = no LWM , 1 = LWM)	OECD International Regulation Database
Minimum consumption threshold, MCT	Minimum consumption threshold for consumers to be allowed to choose their electricity supplier (0 = no choice , 1 = more than 1000 gigawatts (GW), 2 = between 500 and 1000 GW, 3 = between 250 and 500 GW, 4 = less than 250 GW, 5 = no MCT)	OECD International Regulation Database
Public ownership, PO	Ownership structure of the largest companies in the generation, transmission, distribution and supply segments of the electricity industry (0 = private, 1 = mostly private, 2 = mixed, 3 = mostly public, 4 = public)	OECD International Regulation Database
Per-capita consumption, CON	Per-capita consumption of electricity	OECD
Long-term interest rate, R	Long-term interest rate	OECD

Table 2a: Descriptive statistics for investments and final consumer prices by country

Country	I_t/K_{t-1} *(1998-2007)*			P_t *(1998-2007)*		
	Mean	*Min*	*Max*	*Mean*	*Min*	*Max*
AT	0.0405	0.0269	0.0526	0.1099	0.1000	0.1300
BE	0.0650	0.0574	0.0712	0.1300	0.1290	0.1310
CZ	0.0380	0.0283	0.0480	0.1334	0.0830	0.1750
DK	0.0634	0.0321	0.1261	0.0801	0.0600	0.1010
FIN	0.0437	0.0190	0.0712	0.0705	0.0630	0.0810
FR	0.1004	0.0787	0.1221	0.0948	0.0920	0.1000
GER	0.0391	0.0353	0.0457	0.1456	0.1190	0.1880
HU	0.0639	0.0545	0.0704	0.1582	0.1060	0.2140
ITA	0.0662	0.0487	0.0872	0.1395	0.1250	0.1580
NOR	0.1150	0.0833	0.1541	0.0520	0.0370	0.0780
POL	0.0447	0.0369	0.0526	0.1461	0.1200	0.1690
POR	0.0522	0.0225	0.0897	0.1960	0.1810	0.2200
SK	0.0385	0.0166	0.0530	0.1713	0.0680	0.2280
SP	0.4253	0.2114	0.6916	0.1429	0.1320	0.1780
SWE	0.0530	0.0376	0.0786	0.0505	0.0480	0.0530
UK	0.0937	0.0778	0.1148	0.1206	0.1060	0.1610
ALL	**0.0885**	**0.0166**	**0.6916**	**0.1249**	**0.0370**	**0.2280**

Table 2b: Regulatory variables and Ownership

Country	***Ownership unbundling OU***	***Third party access TPA***		***Liberalized wholesale market LWM***	***Minimum consumption threshold MCT***	***Public Ownership PO***				
		Regulated	*Negotiated*		*No threshold*	*Private*	*Mostly Private*	*Mixed*	*Mostly Public*	*Public*
	Since	*Since*	*Since*	*Since*	*Since*	*Since*	*Since*	*Since*	*Since*	*Since*
AT	No	1999		2002	2001				1975	
BE	No	2000		No	2007		1975			
CZ	2005	2000		2000	2006				2004	1975
DK	2005	1999		1996	2002				1975	
FIN	1997	1995		1996	1997			1999	1975	
FR	No	2000		2002	2007				2006	1975
GER	No	2006	1990	2000	1998	1998		1975		
HU	No*	2002		2003	2007			1996		1975
ITA	2004	1999		2004	2007**			2005	2000	1975
NOR	2002	1991		1991	1991			2007	1975	
POL	2007	2000		No	2007				1999	1975
POR	2003	2000		2002	2002			1999	1989	1975
SK	2006	1999		No	2007				2004	1975
SP	2002	1999	1994	1999	2002			1975	1997	
SWE	1996	1996	1991	1996	1996					1975
UK	2000	1996	1992	1990	1998	1995			1990	1975

* *OU* from 2004 until 2005 in Hungary.

**Between 2002 and 2003 no *MCT* in Italy, from 2004 until 2006 the threshold was one gigawatt.

TPA: Before regulated or negotiated TPA has been introduced in a country, there was always no TPA.

PO: The first year captured by OECD International Regulation Database is 1975.

Table 3a: Determinants of investments

Dependent Variable: I_t/K_{t-1}	FE ECM	FE Without ECM	GMM-DIFF ECM	GMM-DIFF Without ECM
I_{t-1}/K_{t-2}			0.1809**	0.2855***
			(0.0745)	(0.0706)
$Log\ P_{t-1}$	0.0159	0.2000	-0.1937*	-0.1265
	(0.0713)	(0.1377)	(0.1177)	(0.1232)
$Log\ P_{t-2}$	0.0215	0.2058	0.3134**	0.5349**
	(0.0823)	(0.1696)	(0.1388)	(0.2079)
OU_{t-1}	0.0041	-0.0435	0.0154	-0.0125
	(0.0227)	(0.0456)	(0.0228)	(0.0266)
OU_{t-2}	-0.0232	-0.0701***	-0.0552**	-0.0552***
	(0.0176)	(0.0158)	(0.0217)	(0.0210)
TPA_{t-1}	0.0062	-0.0160	-0.0162	-0.0276
	(0.0125)	(0.0150)	(0.0171)	(0.0208)
TPA_{t-2}	0.0010	-0.0094	-0.0349*	-0.0136
	(0.0130)	(0.0313)	(0.0205)	(0.0250)
LWM_{t-1}	0.0170	0.0811*	0.0359	0.0734**
	(0.0158)	(0.0450)	(0.0238)	(0.0324)
LWM_{t-2}	-0.0179	-0.0111	-0.0165	0.0028
	(0.0161)	(0.0252)	(0.0203)	(0.0149)
MCT_{t-1}	-0.0004	0.0209*	0.0273	0.0354*
	(0.0055)	(0.0117)	(0.0166)	(0.0201)
MCT_{t-2}	-0.0038	-0.0138*	-0.0147*	-0.0235***
	(0.0041)	(0.0068)	(0.0076)	(0.0087)
PO_{t-1}	-0.0295**	-0.0340*	-0.0402**	-0.0540***
	(0.0106)	(0.0184)	(0.0156)	(0.0174)
PO_{t-2}	0.0058	-0.0592*	0.0800*	0.0232
	(0.0146)	(0.0332)	(0.0410)	(0.0221)
$\text{Log}\,\Delta CON_t$	0.1409	0.4717	0.9507***	0.7235***
	(0.3709)	(0.2812)	(0.3559)	(0.2761)
$\text{Log}\,\Delta CON_{t-1}$	0.0909	0.1363	0.5476	-0.1278
	(0.2294)	(0.5784)	(0.4112)	(0.5241)
$\text{Log}\ r_{t-1}$	-0.0172	0.0792	0.1865	0.0945
	(0.0701)	(0.1304)	(0.1436)	(0.1423)
$\text{Log}\ r_{t-2}$	0.0707	0.0985	0.0870	0.0266
	(0.0593)	(0.0837)	(0.0621)	(0.0420)
$Log\ K_{t-2}$	-0.1841***		-0.2072***	
	(0.0168)		(0.0406)	
$Log\ C_{t-2}$	0.1038		1.1149***	
	(0.1647)		(0.4134)	
AR(1) p-value			0.0693	0.0676
AR(2) p-value			0.1546	0.0969
Sargan p-value			0.3061	0.1508
Time dummies	Yes	Yes	Yes	Yes
No. of instruments			55	53
Observations	75	79	67	67

Robust standard errors in parentheses; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Hausman Tests (Ho: difference in coefficients not systematic): FE ECM vs. GMM-Diff ECM: p = 0.1054 (Ho cannot be rejected); FE no ECM vs. GMM-Diff no ECM: p = 0.1787 (Ho cannot be rejected).

Tab 3b: Short and long-term effects

	FE ECM	FE Without ECM	GMM-DIFF ECM	GMM-DIFF Without ECM
Short log P	0.0373	0.4057 (p=0.121)	0.1196*	0.4084**
Long log P			0.1461*	0.5716***
Short OU	-0.0191 (p=0.126)	-0.1135*	-0.0398**	-0.0676**
Long OU			-0.0486**	-0.0946***
Short TPA	0.0072	-0.0254	-0.0511*	-0.0412
Long TPA			-0.0624*	-0.0576
Short LWM	-0.0008	0.0700*	0.0193	0.0761***
Long LWM			0.0236	0.1066***
Short MCT	-0.0041	0.0071	0.0125	0.0118
Long MCT			0.0153	0.0166
Short PO	-0.0237*	-0.0931**	0.0398	-0.0308*
Long PO			0.0486	-0.0431

Short-run coefficient ($\vartheta_1 + \vartheta_2$) for prices; analogous for the other coefficients and variables.
Long-run coefficient ($\vartheta_1 + \vartheta_2$) / ($1 - \rho$) for prices; analogous for the other coefficients and variables.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Tab 4: Robustness: switching countries and never switched countries are considered

	FE ECM	FE Without ECM	GMM-DIFF ECM	GMM-DIFF Without ECM
Short log P	0.0133	0.4104	0.0944	0.3236*
Long log P			0.1132	0.4418**
Short OU	-0.0150	-0.1026*	-0.0101	-0.0642**
Long OU			-0.0122	-0.0876**
Short TPA	0.0175	-0.0000	-0.0516*	-0.0317
Long TPA			-0.0619*	-0.0432
Short LWM	0.0039	0.0851**	0.0279	0.0967***
Long LWM			0.0335	0.1320***
Short MCT	-0.0052	0.0095	0.0165*	0.0179
Long MCT			0.0198*	0.0244
Short PO	-0.0210	-0.0739*	0.0270	-0.0245
Long PO			0.0325	-0.0334
AR(1) p-value			0.0677	0.0757
AR(2) p-value			0.6301	0.0986
Sargan p-value			0.4744	0.3694
Time dummies	Yes	Yes	Yes	Yes
No. of instruments			52	50
Observations	61	63	55	55

Short-run coefficient ($\vartheta_1 + \vartheta_2$) for prices; analogous for the other coefficients and variables.
Long-run coefficient ($\vartheta_1 + \vartheta_2$) / ($1 - \rho$) for prices; analogous for the other coefficients and variables.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Tab 5: Granger causality tests

GMM-Diff	p-value	Ho: ($\vartheta_1 + \vartheta_2$=0)	Answer
P causes I ?	0.004	rejected	Yes
I causes P ?	0.037	rejected	Yes
OU causes I ?	0.004	rejected	Yes
I causes OU ?	0.548	Not rejected	No
TPA causes I ?	0.584	Not rejected	No
I causes TPA ?	0.942	Not rejected	No
LWM causes I ?	0.000	rejected	Yes
I causes LWM ?	0.474	Not rejected	No
MCT causes I ?	0.243	Not rejected	No
I causes MCT ?	0.103	rejected	Yes
PO causes I ?	0.002	rejected	Yes
I causes PO ?	0.007	rejected	Yes

($\vartheta_1 + \vartheta_2$) for prices; analogous for the other coefficients and variables.

Tab 5: Long and short-term results taking account of (possible) endogeneity

	GMM-DIFF Without ECM	GMM-DIFF Without ECM	GMM-DIFF Without ECM
	P end.	**P, MCT and PO end.**	**P and all reg. var. end.**
Short log P	0.3637*	0.2882*	0.3422**
Long log P	0.5097*	0.4071**	0.4866**
Short OU	-0.0768**	-0.0765**	-0.0662**
Long OU	-0.1076***	-0.1081***	-0.0941***
Short TPA	-0.0563	-0.0571	-0.0590
Long TPA	-0.0790	-0.0807	-0.0839
Short LWM	0.0725**	0.0770**	0.0656**
Long LWM	0.1016**	0.1087***	0.0933**
Short MCT	0.0161	0.0161	0.0167
Long MCT	0.0226	0.0228	0.0237
Short PO	-0.0313*	-0.0425*	-0.0301
Long PO	-0.0439	-0.0601*	-0.0428
AR(1) p-value	0.0697	0.0674	0.0763
AR(2) p-value	0.1073	0.1105	0.1410
Sargan p-value	0.2823	0.3877	0.6384
Time dummies	Yes	Yes	Yes
No. of instruments	58	60	67
Observations	67	67	67

Short-run coefficient ($\vartheta_1 + \vartheta_2$) for prices; analogous for the other coefficients and variables.
Long-run coefficient ($\vartheta_1 + \vartheta_2$) / ($1 - \rho$) for prices; analogous for the other coefficients and variables.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.