Regulation and Technical Efficiency in the Electricity Industry: Evidence from some European Union Countries

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ABSTRACT: This paper focuses on the relationship between the stringency of regulation (OECD indicators) and total factor productivity (TFP) growth in the electricity sectors of 19 EU countries for the period 1994-2007. Both the OECD regulatory indicator and the TFP growth index have been decomposed in order to bring to light a complex picture of interrelations in which the negative impact of the overall regulation on productivity is the result of opposite forces. Estimation results tell us that only the stringency of entry regulation significantly reduces technological change, whereas vertical integration exhibits a negative and significant impact only on the catching up process (pure efficiency change). Lastly, we found an interesting result concerning the explanatory variables of the scale efficiency change: in this case only public ownership matters, in other terms high levels of public in the structure ownership of electric companies guarantee improvements in reaching the optimal scale of production.

JEL Classification: L51; L94; O47

Keywords: Electricity; total factor productivity growth; regulation

1. Introduction

The last two decades have been characterized by a common view of economic policy, both in developed and in developing countries, that is favorable to restructuring, liberalizing and privatizing the electricity sector. In the European Union, the experience of the UK as trailblazer of liberalization in this sector, stimulated the adoption of three electricity

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directives (1996/92/EC; 2003/54/EC; 2009/72/EC) that gradually faced different aspects, but maintained the same long-term and overriding goal to transform individual state-owned monopolies into one single competitive EU electricity market (Jasmab and Pollit, 2005; Littlechild, 2006; Haas *et al.*, 2006; Joskow, 2008; Pollit, 2009). This effort has been recently acknowledged as a formidable pro-competitive reform program "[…] unmatched in scale and depth in any other major region of the world." (Pollit, 2009, p.1). In particular, EU reforms place emphasis on unbundling networks from generation and retailing, on reducing collusion among large companies and eliminating entry barriers, on guaranteeing an independent regulation authority and adequacy of supply. Consequently, a huge number of studies have concentrated on the post-reform performances of the electricity sectors around the world and within the EU. Most of these studies have dealt with the price and welfare effects of the liberalization and focused, from time to time, on one or a handful of countries. Very often, the reason for limiting oneself to study few countries was to avoid the distortions that arise when one performs large cross-country price-effect assessments. For example, some authors perceptively pointed out that lack of information regarding different fuel cost regimes, could lead to meaningless cross-country comparisons of electricity prices, before and after the reforms (Joskow, 2006b; Harvey *et al.*, 2006). The few remaining studies accomplished larger cross-country comparisons in which physical measures of efficiency were used and the European Union countries were included as a small group, along with other developed, emerging and less developed countries. Thus, to the best of our knowledge, updated cross-country comparisons are lacking, especially those that address the effect of reforms on the technical efficiency of the generation sector in the European countries.

This paper aims to fill this gap. More precisely, we investigated the relationship between regulation levels (OECD indicators) and total factor productivity (TFP) growth in the electricity generation sectors of 19 EU countries for the period 1994-2007. Both the OECD regulatory indicator and the TFP growth index have been decomposed, in order to show the complex picture of interrelations in which the negative impact of regulation on productivity is the result of opposite forces. First of all, the empirical analysis develops over two stages. In the first stage we estimated a Malmquist index of TFP for the electricity sector of 19 countries and decomposed it into: *i)* technological change, that is the shift in the efficient technological frontier; *ii*) pure efficiency change, that is improvement or worsening of the *catching up* process; and *iii*) scale efficiency change, that is improvement or worsening in reaching the optimal scale of production.

In the second stage we regressed the Malmquist TFP index and its components on the overall OECD regulatory indicator and on its low-level indicators: a) entry regulation, b) public ownership and c) vertical integration. Entry regulation measures the level of barriers against third party access; *public* describes the ownership structure of the largest companies operating in the sector, whereas vertical integration is inversely correlated to the degree of separation between the transmission and generation segments.

The aim of this paper is to contribute to the debate developing around the effects of EU pro-competitive reforms in the electricity sector by confirming some benefits that they produce on the general level, but also by discovering some contradictions. The latter emerge because a more complex picture of interrelations, stemming from the double decomposition mentioned above, is taken into account. Especially in an era in which the efficiency concerns are accompanied by reflections on the real ability of the market "[…] to deliver the large quantities of investment which are predicted as being necessary to decarbonize the sector and to meet energy security concerns" (Pollit, 2009, p.1), policy makers should pay more attention to these contradictory effects. The remainder is organized as follows. A survey of the literature and conceptual bases of the empirical analysis are discussed in section 2. Section 3 is dedicated to the first stage, in which we present data sources, descriptive statistics and estimations of the Malmquist index of TFP. The second stage, that is the evaluation of the impact of regulation on TFP growth of the electricity sector, is treated in section 4, whereas some concluding remarks are presented in section 5.

2. Literature review and conceptual framework of the empirical analysis

A survey that addresses exhaustively the vast literature that deals with the post-reform performance of the electricity sector is out of the scope of this paper[1]. Therefore, according to the aims declared in the introduction, we will limit our discussion to the recent articles taking into account physical measures of efficiency and/or OECD regulatory indicators. This decision is basically motivated by two key reasons underlying cross-country comparison that, in turn, results to be one of the most important approaches to examine the effects of the liberalization reform (Joskow,

[1] Comprehensive reviews are found in Sioshansi and Pfaffenberger (2006) and Joskow (2008).

2006a; 2008). The first reason has been already discussed above and relates to resorting to physical measures of performance in the electricity sector, in order to avoid the distortions that arise when we perform cross-country price-effect assessments. The second reason concerns the need to use harmonized indicators of regulation in between-countries econometric investigations. In this field, the indicator of regulation in the electricity sector, stemming from the vast methodological study on product market regulation (PMR) in OECD countries, seems to be the most suitable (Conway and Nicoletti, 2006; Wölfl et al., 2009).

Starting from these considerations, it is worth noting the survey of Steiner (2001); this author analyzes the effect of the first wave of reforms (1986-1996 period) on 19 OECD countries, of which 13 are European Union countries. Besides electricity prices, he considers physical measures of efficiency in electricity generation, such as the capacity utilization rate and the distance of actual from the optimal reserve margin. He also constructs 8 harmonized regulatory indicators relying on an *ad hoc* OECD questionnaire and finds a positive impact on the technical efficiency generated by privatization and vertical separation of generation from transmission companies. Fiorio et al.(2007) focus on the EU-15 countries and study a longer period, from 1975 to 2005. Even though these authors only consider the retail electricity price for households as a measure of performance, they use the regulatory indicator, and its three sub-components, elaborated within the PMR research program of the OECD. This study is of interest because the results are not univocal: only entry regulation is found to raise electricity prices, whereas the levels of public ownership and vertical integration play no role on the price levels. Also in a more recent paper (Erdogdu, 2011), that considers as efficiency measures the net electricity generation per employee and electricity losses as fraction of power generated, the results are not univocal. Indeed, this author includes in his empirical investigation 92 economies, of which 21 are EU countries, for the period 1982-2008, and finds that his own calculated electricity market reform scores have a positive impact on labor productivity, but at the same time the reform steps seem to have increased average electricity losses. Similarly, Zhang et al. (2008) estimate the impact of the electricity market reforms on electricity generation per employee in 36 developing and transitional economies for the period 1985-2003. They find that only increasing competition has a positive impact on labor productivity, whereas privatization and other deregulation forms do not.

Other studies are worth noting because they use a refined index for technical productivity such as the Malmquist index of TFP (Hattori et al.,

2005; Abbot, 2006; Estache et al., 2008; Nakano and Managi, 2008; Perez-Reyes and Tovar, 2009; Ramos-Real et al., 2009). Even though they are almost all company level analyses, focusing on the electricity distribution segment, concentrating on within-country or performing comparisons between two countries at the most, their methodological approach is interesting. First of all, these authors, by relying on a no-parametric method such as Data Envelopment Analysis (DEA), decompose the overall TFP growth rate in three components: i) technological change; ii) pure efficiency change and iii) scale efficiency change.

So doing, they obtain a more complex picture of the effect of reforms on TFP change. In particular, there are two studies that use a mixed approach: 1) no-parametric estimation (DEA method) of TFP growth rate and its components, in the first step; 2) econometric analysis in which they regress the output of the first step on the regulation indicators, in the second step. According to this strategy, Nakano and Managi (2008) find for Japanese companies a positive impact of the liberalization reforms only on technological change, but not on efficiency change. In a similar way, Perez-Reyes and Tovar (2009) deal with the Peruvian distribution companies and highlight that privatization sharply improved the frontier shift (technological change), whereas a more modest impact was found on the pure and scale efficiency change.

Our paper moves towards the methodological approach proposed in Nakano and Managi (2008) and Perez-Reyes and Tovar (2009). Thus, firstly, we estimate the TFP growth rate of net electricity generation for 19 EU countries between 1994 and 2007, and decompose the overall TFP change in the frontier shift (technological change), *catching up* (pure efficiency change) and improvements in reaching the optimal scale of production (scale efficiency). Secondly, we regress these technical efficiency indexes on the OECD regulatory indicator for the electricity sector, that in turn is decomposed into three components: liberalization (regulation of new entrants), degree of public ownership and degree of vertical integration between the generation and transmission segments.

The basic idea is that the general negative effect of the overall OECD indicator on TFP growth in the electricity sector, disguises some trade-offs emerging when a more detailed analysis is taken into account. For example, the positive effect of low entry barriers on that part of TFP growth due to the frontier shift, that is technological change, is widely acknowledged in the literature, both from the theoretical (Dasgupta and Stiglitz, 1980; Gilbert and Newbery, 1982; Reinganum, 1983) and from the empirical (Unger, 2010) point of view. As regards the vertical integration degree, some authors argued that by separating the generation and transmission

segments, substantial market uncertainties causing transactional costs to rise could be generated (Kaserman and Mayo, 1991). On the other hand, if we adopt the *strategic management* view, vertical disintegration could lower management and coordination costs and improves specialization and corporate coherence (Teece and Rumelt, 1994), hence pure efficiency increases. In addition, Newbery (1997) discusses the specific case of the electricity sector from the *interest group theory of regulation* view and argues that maximizing the extent of vertical integration is the best way to create and protect rents for distribution to the incumbent interest groups. He also associates these incumbent interest groups with the high cost domestic fuel producers; hence, when these suppliers are protected, technical inefficiency rises in the generation segment.

These considerations lead us to formulate a non *a-priori* hypothesis relating to the effect of the degree of vertical integration on technological change and pure efficiency. Eventually for public ownership, that is the third component of the overall OECD regulatory indicator, theory allows us to formulate a specific hypothesis, at least concerning scale efficiency change. Indeed, both Newbery (1997) and Sappington and Stiglitz (1987) pointed out that public ownership could be the efficient solution when the regulator cannot guarantee private investors an adequate return on their investment. On the other hand, Haney and Pollit (2010) concede that climate change and related policies impose significant new investment requirements on the power sector. More precisely, investments in alternative low fossil fuel technologies expose investors to many risks, especially when the payback periods for these investments are long (20-30 years). Like during the electrification period in the early Twentieth Century, public ownership could result in being the best solution to insure the large scale investments that the generation sector requires in this new era.

We can sum up the considerations above, by formulating some testable hypotheses:

H1: *the effect of overall electricity sector regulation, described by the OECD indicator, can hide counterbalancing second level effects*, in which some aspects of regulation countervail the effects of some other aspects in explaining the growth rate of the components of TFP (technological change, pure efficiency change, scale efficiency change). In particular, theory allows us to hypothesize some second level effects such as the following:

H2: *the more stringent the entry regulation, the lower the technological change growth rate.* Hence, we expect a negative impact of the entry

barriers on the technological frontier shift;

H3: *public ownership exerts a positive influence on the scale efficiency change*.

3. Technical efficiency of the electricity supply industry in some EU countries

This section deals with the first stage of our empirical analysis concerning the estimation of the Malmquist index of TFP, based on Data Envelopment Analysis (DEA). Subsection 3.1 is dedicated to an outline of this approach, while in 3.2 we discuss the data sources and show some preliminary and descriptive statistics. Eventually, subsection 3.3 shows the estimated results.

3.1 Malmquist index of TFP using DEA frontiers

Following Farrell (1957), Färe *et al.* (1994) and Coelli *et. al* (2005) we define productivity change as the geometric mean of the indices based on period t and period t+1 technologies that, in turn, are two output-based Malmquist productiviy indexes:

$$M_i(\mathbf{X}_i^{t+1}, y_i^{t+1}, \mathbf{X}_i^t, y_i^t) = \left[\left(\frac{D_i^{t+1}(\mathbf{X}_i^{t+1}, y_i^{t+1})}{D_i^{t+1}(\mathbf{X}_i^t, y_i^t)}\right)\left(\frac{D_i^t(\mathbf{X}_i^t, y_i^t)}{D_i^t(\mathbf{X}_i^{t+1}, y_i^{t+1})}\right)\right]^{1/2} \quad (1)$$

Where $\mathbf{X}_i^t$ and $\mathbf{X}_i^{t+1}$ are the vectors of inputs in years t and t+1;

y_i^t and y_i^{t+1} are the outputs in years t and t+1;

Each distance function D_i is estimated by means of a DEA-like linear programming method in the context of an output-orientated model (Coelli et *al*.,2005).

If we assume that electricity sectors can be inefficient and, in addition, relax the constant return to scale (CRS) assumption, we identify the three different sources of TFP growth largely discussed in previous sections: i) technological change; ii) pure efficiency change (or *catching up*); iii) scale efficiency change, that measures the improvements in the scale of operations of the electricity sectors and its move towards a technologically

optimum scale of operations. In other terms we can rewrite equation (1) as follows:

$$M_i(\mathbf{X}_i^{t+1}, y_i^{t+1}, \mathbf{X}_i^t, y_i^t) = \frac{D_i^{t+1}(\mathbf{X}_i^{t+1}, y_i^{t+1})}{D_i^t(\mathbf{X}_i^t, y_i^t)} \times \left[\left(\frac{D_i^t(\mathbf{X}_i^{t+1}, y_i^{t+1})}{D_i^{t+1}(\mathbf{X}_i^{t+1}, y_i^{t+1})}\right)\left(\frac{D_i^t(\mathbf{X}_i^t, y_i^t)}{D_i^{t+1}(\mathbf{X}_i^t, y_i^t)}\right)\right]^{1/2} \quad (2)$$

Where

$\frac{D_i^{t+1}(\mathbf{X}_i^{t+1}, y_i^{t+1})}{D_i^t(\mathbf{X}_i^t, y_i^t)}$ is the ratio of distance functions measuring overall efficiency change;

$\left[\left(\frac{D_i^t(\mathbf{X}_i^{t+1}, y_i^{t+1})}{D_i^{t+1}(\mathbf{X}_i^{t+1}, y_i^{t+1})}\right)\left(\frac{D_i^t(\mathbf{X}_i^t, y_i^t)}{D_i^{t+1}(\mathbf{X}_i^t, y_i^t)}\right)\right]^{1/2}$ is the term measuring technological change.

The overall efficiency change, in turn, can be decomposed into pure efficiency change and scale efficiency change[2]. Lastly, from period *t* to *t+1* the Malmquist index of TFP is the result of these three sources of growth:

$$M_i(\mathbf{X}_i^{t+1}, y_i^{t+1}, \mathbf{X}_i^t, y_i^t) = \text{(Pure eff. change) x (Scale eff. change) x (Tech. change)}$$

3.2 Data sources and preliminary descriptive statistics

The TFP growth estimation is based on the physical quantities of three inputs and one output, relating to the electric power sector of 19 EU countries between 1994 and 2007. Total net electricity production is the output, while labor (hours worked), fuels and installed capacity are the inputs we used. Due to a lack of data, we had to limit our analysis to a subsample of EU member countries and we were not able to extend the period before 1994. According to Abbott (2005) and the literature quoted in section 2, the amount of fuel used to generate electricity is the variable that best describes raw materials, whereas the installed capacity is a traditional proxy of capital, due to the difficulties in measuring this input in the generation segment. Net electricity production (NEP), fuels and installed capacity come from the Eurostat Energy Database (codes nrg_105a, nrg_100a, nrg_113a). More precisely, NEP is measured in *gigawatts per*

[2] In order to save space we do not formally show this last decomposition. For details see (Coelli et al., 2005).

hour and is equal to gross electricity production less the electrical energy absorbed by the generating auxiliaries and the losses in the main generator transformers. Gross electricity, in turn, derives from both public production and auto-producers and refers both to electricity only and to combined power and heat (CHP) plants. The term fuel means the amount of combustible fuels measured in *terajoule* and used to produce electricity in the plants mentioned above. These inputs correspond to those mentioned in table 6 of the Electricity & Heat Annual Questionnaire released by Eurostat and are coherent with the estimations of the thermal efficiency reported in Eurostat (2010). Installed capacity is measured in *megawatts*. Hours worked have been collected from EU-KLEMS Database.

The table 1 shows output and partial productivities in the countries under scrutiny. The ranking of the top five largest producers of NEP in Europe did not change between 1994 and 2007 and reflects the economic size of the countries: Germany is at the top, followed by France, the United Kingdom, Italy and Spain. It is worth noting that according to Eurostat (2010) only Germany, France and Spain are the largest net exporters, whereas Italy and the United Kingdom are important electricity net importers. In the same period there was a substantial increase in production in Luxembourg (10.4%), as well as Spain (5.05%), Ireland (4.03%), Greece (3.59%), Portugal (3.28%) and Czech Republic (3.08%). Nonetheless, only for Spain and the Czech Republic did these improvements change the status of country from net importer to net exporter (Eurostat, 2010).

As partial productivities we considered a measure of fuel conversion efficiency (or thermal efficiency) very similar to that reported in Eurostat (2010)[3], labor productivity (GWh produced per thousand hours worked) and capacity utilization, that is the ratio between NEP and power installed[4].

Although in Germany and France the NEP increased less than the average of the total sample (1.54% and 1.38% respectively, versus 2.16%), these two countries improved partial productivities remarkably. In particular Germany shows very good performances in fuel conversion efficiency, capacity utilization and labor productivity, even though the latter resulted to be increasing below the sample average. The importance of nuclear power stations in France negatively influences its thermal efficiency (ABB, 2011; Eurostat, 2010; Graus and Worrell, 2007), but positively relates to capacity utilization and labor productivity.

[3] The difference is in the numerator: we used net, instead of gross electricity production.

[4] Due to lack of information on hours of plant utilization, the capacity utilization rate is not a pure number, but an approximation of the average number of hours that plants work.

Table 1 Net Electricity Output and Partial Productivities

Countries	Total Net Electricity Production (NEP) 1994 (GWh)	2007 (GWh)	*Average Annual Var. 2007-1994 (%)*	Fuel Conversion Efficiency NEP (TJ)/Fuels used (TJ) 1994 (%)	2007 (%)	*Average Annual Var. 2007-1994 (%)*
Germany	490899	598435	1.54	0.37	0.43	1.16
France	455778	544566	1.38	0.39	0.32	-1.49
United Kingdom	308987	379141	1.59	0.37	0.43	1.10
Italy	220172	301299	2.44	0.37	0.50	2.33
Spain	154640	293229	5.05	0.37	0.44	1.46
Poland	122853	145383	1.30	0.38	0.43	0.95
Sweden	138907	145133	0.34	0.83	0.87	0.37
Netherlands	76476	100851	2.15	0.56	0.60	0.61
Belgium	68509	85098	1.68	0.44	0.51	1.24
Czech Republic	54853	81412	3.08	0.42	0.43	0.27
Finland	62175	77825	1.74	0.72	0.67	-0.59
Austria	51814	62738	1.48	0.51	0.57	0.84
Greece	37379	59088	3.59	0.34	0.36	0.56
Portugal	30192	45908	3.28	0.40	0.45	0.89
Denmark	38265	37355	-0.18	0.51	0.54	0.42
Hungary	30959	37220	1.43	0.42	0.46	0.81
Ireland	16114	26945	4.03	0.38	0.44	1.20
Slovakia	22721	25766	0.97	0.39	0.46	1.16
Luxembourg	1107	3960	10.30	0.59	0.53	-0.85
Total Countries	*2382800*	*3051352*	*2.16*	*0.46*	*0.50*	*0.61*

Countries	Labour Productivity NEP (GWh) / Hours Worked (,000) 1994 (GWh)	2007 (GWh)	*Average Annual Var. 2007-1994 (%)*	Utilisation Capacity NEP (GWh)/Installed Capacity (GW) 1994 (Hours)	2007 (Hours)	*Average Annual Var. 2007-1994 (%)*
Germany	1.16	1.91	3.90	2416	3918	3.79
France	1.76	2.50	2.74	2923	3807	2.05
United Kingdom	1.50	2.68	4.57	2451	2417	-0.11
Italy	1.09	3.05	8.23	1906	1625	-1.22
Spain	1.91	5.52	8.50	2185	2701	1.64
Poland	0.58	0.88	3.33	2097	2245	0.53
Sweden	3.60	4.64	1.97	3154	2340	-2.27
Netherlands	1.77	2.59	2.96	2103	2180	0.28
Belgium	2.07	3.69	4.57	2804	3111	0.80
Czech Republic	0.51	3.29	15.41	2191	2569	1.23
Finland	3.01	4.05	2.30	2553	2403	-0.46
Austria	0.87	1.89	6.12	1855	1583	-1.21
Greece	0.76	1.67	6.28	2387	2221	-0.55
Portugal	0.93	3.55	10.90	2140	1630	-2.07
Denmark	2.25	3.35	3.09	1886	1590	-1.30
Hungary	0.37	1.35	10.45	2416	2391	-0.08
Ireland	6.46	4.91	-2.09	2062	1932	-0.50
Slovakia	0.40	1.41	10.31	2850	2042	-2.53
Luxembourg	0.95	2.96	9.14	464	1182	7.45
Total Countries	*1.68*	*2.94*	*5.77*	*2254.89*	*2309.85*	*0.19*

Sources: Own calculations from EU-KLEMS and Eurostat (codes nrg_105a, nrg_100a and nrg_113a).

There are many countries, such as Italy, Spain, Austria, Portugal, the Czech Republic, Hungary and Slovakia that significantly ameliorated labor productivity and thermal efficiency in the 1994-2007 period. However, only those that also improved utilization capacity at the same time, Spain and the Czech Republic, seem to have gained a position as net exporter (Eurostat, 2010).

In any case, partial productivities are very rough measures of efficiency because they do not consider the contribution of the whole input set to the production and do not take into account differences between those that are operating on the efficiency frontier and those that are not. For these reasons we estimated total factor productivity (TFP) by means of a distance functions method such as the data envelopment analysis (DEA).

3.3 Estimation results of the TFP growth rate and its components

The estimated Malmquist index (TFPch) is reported in table 2 as the average annual percentage change between 1994 and 2007. Spain resulted to be the country with the best performance, followed by Germany and France. Indeed, this result is not surprising because all these countries heavily restructured the generation segment plants in the last years of the period under investigation (Haas et al., 2006).

Decomposition analysis shows that *catching up* (that is pure efficiency change) explains the largest part of the TFP growth in Spain: 1.99% out of 3.23%. Probably, the increasing diffusion of an affirmed and efficient technology such as the combined cycle gas turbine (CCGT) has played an important role in the Spanish electric power sector (Dominguez and Bernat, 2007). The good performance of TFP in the two largest electricity markets in Europe, Germany and France, is due to different sources of growth. In France the shift in the technological frontier is the most important factor that boosted TFP growth, while in Germany scale efficiency improvements have played a major role. Indeed, some authors have highlighted the positive influence that mergers and acquisitions had in the German electric power segment in recent years: the achievement of an optimal scale of operations seems to have been the crucial aim of the electricity producers in this country (Haas et al., 2006,; Keller, 2010). It is worth noting that both Germany and France remained on the efficient frontier during the period examined; the nil value of pure efficiency change signals that they have been leaders in technology. Nonetheless, they move along different technological paradigms: nuclear power plants mainly support electricity generation in France, whereas a more balanced fuel mix (nuclear, thermal

and renewables) characterizes production in Germany (Eurostat, 2010).

We can observe that higher values of labor productivity in the Mediterranean countries (Greece, Portugal and Italy), as results from table 1, do not automatically guarantee good performance in the TFP growth. The negative variation of this productivity measure is explained by different motivations. For example, in Italy the catching up contribution was not enough to compensate for the negative role played by technological change and scale inefficiencies. The negative role of technological change also outweighed scale efficiency in Portugal. Lastly, in Greece the decrease in TFP was basically conditioned by a slowdown in the catching-up process.

Table 2 Average Malmquist productivity growth rate and decomposition

	TFPch = TCch +PEch + SEch			
Country	TFPch (%)	*TCch (%)*	*PEch (%)*	*SEch (%)*
Spain	3.23	0.36	1.99	0.87
Germany	2.57	0.50	0.00	2.07
France	1.77	1.18	0.00	0.58
Belgium	1.67	0.75	0.67	0.24
Denmark	1.43	0.46	1.00	-0.07
Czech Republic	1.21	-0.35	1.44	0.13
Luxembourg	0.92	1.83	0.00	-0.91
Netherlands	0.49	-1.31	1.86	-0.02
Poland	0.37	-0.59	0.79	0.17
United Kingdom	0.27	0.07	0.67	-0.46
Austria	0.21	-0.48	0.80	-0.08
Finland	0.18	-0.42	0.69	-0.09
Sweden	0.16	0.16	0.00	0.00
Hungary	-0.01	-0.43	0.48	-0.07
Portugal	-0.02	-0.45	0.02	0.41
Greece	-0.19	0.48	-0.82	0.15
Italy	-0.73	-1.47	1.70	-0.94
Slovakia	-1.37	0.23	-1.70	0.11
Ireland	-1.71	-1.04	-0.05	-0.63

Note: TFPch = Total Factor Productivity change; TCch = Technological change,; PEch = Pure Effficiency change; SEch = Scale Efficiency change. All values are geometric means of the year-by-year estimations from 1994/1995 to 2006/2007.

4. The effects of regulation on productivity growth: an econometric analysis

This section focuses on the second stage of the empirical analysis, in which we investigate the effects of regulation on TFP growth by means of a parametric approach. More precisely, sub-section 4.1 concentrates on the econometric strategy and discusses some drawbacks of the two-stage approach; in 4.2 OECD regulatory indicators for the electricity sector are presented as well as the sources and nature of some control variables. Eventually, econometric results of the above mentioned effects are reported in part 4.3.

4.1 The parametric approach in the second stage: dynamic panel data model

There are well-known problems in dealing with the Malmquist TFP index as dependent variable in econometric specifications. Although the Malmquist index does not suffer from boundary problems like the ones in DEA efficiency scores, its estimates are seriously affected by serial correlation (Simar and Wilson, 2007). This problem can be solved by implementing a bootstrap procedure in the first stage (Simar and Wilson, 2007) or by using econometric methods able to control for serial correlation. Indeed, some authors suggested the dynamic GMM model to eliminate problems of serial correlation in a context where TFP measure estimated by DEA is used as dependent variable (Zhengfei and Oude Lansink, 2006; Nakano and Managi, 2008).

The dynamic panel data specification is also validated in our case because there is a need for the lagged dependent variable to govern the speed of adjustment of the dynamic effect of regulation on TFP growth. Indeed, the lagged dependent variable resulted to be significant in all the auto-regressive models we ran.

Starting from the above considerations, in the first regression we analyzed the effects of regulation on the Malmquist index of TFP according to the Arellano and Bond (1991) specification. The starting point is the following:

$$TFP_{i,t} = \alpha TFP_{i,t-1} + \beta_1 REGEL_{i,t} + \sum_{j=1}^{n} \gamma_j X_{j,i,t} + \eta_i + \theta_t + \epsilon_{i,t} \quad (3)$$

where

i=1, …19 sector-countries

t = 1995, ….2007

j=1,…3 number of control variables
$TFP_{i,t-1}$ is the lagged dependent variable
$REGEL_{i,t}$ is the overall OECD regulatory indicator for the electricity sector
$\sum_{j=1}^{n} X_{j,i,t}$ is the set of control variables
η_i is the individual unobserved effect
θ_t are the time dummies
$\epsilon_{i,t}$ is the idiosyncratic error

Lagged TFP is correlated by construction with panel level effects and lagged ϵ. In addition, the presence of serial correlation causes lagged TFP to be correlated also with contemporaneous error term. For these reasons lagged TFP needs to be treated as an endogenous variable. The difference GMM applies a first differencing in equation (3) and suggests internal instruments of lagged TFP:

$$\Delta TFP_{i,t} = \alpha \Delta TFP_{i,t-1} + \Delta REGEL_{i,t}\beta_1 + \sum_{j=1}^{n} \Delta X_{j,i,t}\gamma_j + \theta_t + \Delta\epsilon_{i,t} \quad (4)$$

In this way, the unobserved individual effect is purged and all observations of dependent variable before t-2 could be valid instruments of $\Delta TFP_{i,t-1}$. However, in our case, as already mentioned, the idiosyncratic errors $\epsilon_{i,t}$ are themselves serially correlated, therefore a valid instruments set of $\Delta TFP_{i,t-1}$ starts with lags 3 and longer. According to Roodman (2009), the time dummies control for correlation across panels in the idiosyncratic errors and help to validate both the Arellano-Bond autocorrelation test and the robust estimates of the coefficient standard errors.

In addition, these transformations do not solve the possible endogeneity problems in which productivity changes affect the regulation level through political economy channels (Nicoletti and Pyror, 2005; Bassanini et al., 2009; Bourlés et al., 2010). In econometric terms it means that $E[REGEL_{i,t}, \epsilon_{i,t-1}] \neq 0$, that is the past error term is correlated with today's regulation level; hence, in order to take into account endogeneity problems, we considered the regulation indicator as a predetermined variable in our model. This in turn means that in the instrument matrix we only included the levels of $REGEL_{i,t}$ for those time periods that are assumed to be unrelated with $\Delta\epsilon_{i,t}$. As we will discuss in the next sub-section, also controls are treated as predetermined variables.

Afterwards, we regressed the three components of the Malmquist TFP

index on the three sub-indicators of the regulation for electricity sector[5]:

$$TCch_{i,t} = \alpha TCch_{i,t-1} + \sum_{z=1}^{n} \beta_z SI_{i,t} + \sum_{j=1}^{n} \gamma_j X_{j,i,t} + \eta_i + \theta_t + \epsilon_{i,t} + \delta\epsilon_{i,t-1} \quad (5)$$

$$PEch_{i,t} = \alpha PEch_{i,t-1} + \sum_{z=1}^{n} \beta_z SI_{i,t} + \sum_{j=1}^{n} \gamma_j X_{j,i,t} + \eta_i + \theta_t + \epsilon_{i,t} + \delta\epsilon_{i,t-1} \quad (6)$$

$$SEch_{i,t} = \alpha SEch_{i,t-1} + \sum_{z=1}^{n} \beta_z SI_{i,t} + \sum_{j=1}^{n} \gamma_j X_{j,i,t} + \eta_i + \theta_t + \epsilon_{i,t} + \delta\epsilon_{i,t-1} \quad (7)$$

where
i=1, …19 sector-countries
t = 1995, ….2007
j=1,…3 number of control variables
z=1,…3 number of regulatory sub-indicators
$TCch_{i,t}$ is the technological change
$PEch_{i,t}$ is the pure efficiency change
$SEch_{i,t}$ is the scale efficiency change
$SI_{i,t}$ are the regulatory sub-indicators
$\sum_{j=1}^{n} X_{j,i,t}$ is the set of control variables
η_i is the individual unobserved effect
θ_t are the time dummies
$\epsilon_{i,t} + \delta\epsilon_{i,t-1}$ is a composite (MA1) error

The GMM difference estimator needs equations (5), (6) and (7) to be transformed as in equation (4). The only difference in this case is that we modeled the error term as a composite (MA1) error because we found autocorrelation of the first order in levels by checking, in the Arellano-Bond test, autocorrelation of the second order in differences (Roodman, 2009).

4.2 Data sources, variables and preliminary descriptive statistics for the dynamic panel data estimation

We basically run four models in which the overall impact (equation 3) and the specific impact of singular aspects of regulation on the three components of TFP growth (equations 5, 6, 7) have been estimated. Our dependent variables are the output of the Malmquist index estimations, largely discussed in section 3. The key explanatory variables are the overall

[5] A detailed discussion of these sub-indicators is reported in sub-section 4.2.

regulatory index for the electricity sector (REGEL) and its three components: the entry regulation (ENTRY), the importance of public ownership (PUBLIC) and the degree of vertical integration (VERTICAL). These indicators stem from the vast OECD research program on product market regulation and show high reliability. Indeed, they are built by means of a bottom-up approach based on information about existing laws and regulations; this information, in turn, derives from a survey of member countries and guarantees a high level of comparability across them (Conway and Nicoletti, 2006; Wölfl et al., 2009). Both REGEL and its three components (ENTRY, PUBLIC and VERTICAL) are based on qualitative information that is coded by assigning a numerical value to each of the possible responses to a given question. The coded information is normalized over a scale of zero to six, reflecting increasing restrictiveness of regulatory provisions on competition. Thus, ENTRY reports scores from zero to six, depending on third party access and the degree of liberalization of the wholesale electricity market. PUBLIC reports, on the same scale, the importance of the state in structure ownership of the largest companies in the segments of this sector, whereas VERTICAL refers to the degree of vertical integration between the transmission and generation segments. Eventually, REGEL sums up these themes by assigning equal weights (Conway and Nicoletti, 2006).

As regards controls, besides time dummies we considered the following three variables: sectoral research and development expenditure intensity (that is R&D expenditure out of value added in the electricity sector); the importance of combined power and heat technology (CHP is the fraction of electricity produced with this technology) and the importance of renewable source technology (RENEN is the fraction of electricity produced with these sources).

R&D intensity is commonly used to control for all the factors that proxy unincorporated technical progress, especially when institutional aspects are the key explanatory variables of TFP growth (Bassanini et al., 2009). We collected these data from the International Energy Agency (IEA) database.

RENEN and CHP are two important technologies that have been rapidly expanding in recent years because they meet the important aims to reduce CO_2 emissions and to raise efficiency (IEA, 2010). Nonetheless, we hypothesized that their specific nature could affect TFP growth more than the other technologies do. Thus, most renewables are intermittent sources (wind, sun, tide, waves), whose supply depends on out-of-control conditions (Ambec and Crampes, 2010), while CHP are usually sized to meet the required heat demand, selling the excess electricity produced back to the grid (IEA, 2010). Since these technologies unevenly penetrated

countries included in our sample, we decided to use the penetration rate as control variable for TFP growth. Both penetration rates, for RENEN and CHP, come from Eurostat Database.

Before discussing the estimation results, it is useful to show some descriptive statistics referring to regulation.

Figure 1 reports a scatter graph of levels of the stringency in overall regulation (REGEL indicator) at the beginning and the end of the period. The lines dividing the graph's plot area indicate the non-weighted averages for the reference years and mark out four different groups of countries. In the South-West quadrant we find a group of five persistently low-regulated countries (whose scores remain below the average in both the reference years): the UK, Finland, Germany, Portugal and Spain. At the opposite North-East quadrant, France, Ireland, Poland, the Netherlands, Slovakia and Greece form a group of persistently highly regulated countries. The main characteristic in common among these countries is the importance of public ownership; despite the effort in liberalization and unbundling (see table 3), it is the too slow decline in public ownership that forces them into the region above the average in both reference years. The remaining EU members are distributed between the North-West and the South-East quadrants. In the first one, we find Sweden and Belgium forming a small group of countries in which moderate deregulation occurred. In the second one, we put four countries around the 2007 average (Denmark, Luxembourg, Austria and the Czech Republic) plus Hungary and Italy. All these nations share more significant deregulation in which a sharp decline, from six to zero, of both entry regulation and vertical integration is evident (see table 3).

If we analyze the trends in the estimated TFP, according to the four groups of countries discussed above, the influence of the overall electricity sector regulation on technical efficiency does not seem so clear (figure 2, panel A and B). For example, in the persistently low-regulated countries only Germany and Spain show excellent performances, even though these are not so much higher than France's TFP growth, a country that belongs to the persistently highly-regulated group. With the exception of Ireland, the remaining highly regulated countries (Greece, the Netherlands, Slovakia and Poland) exhibit an evolution in the TFP index ranging from 90 to 110; this is a very similar pattern to that of other low-regulated countries (the UK, Finland and Portugal).

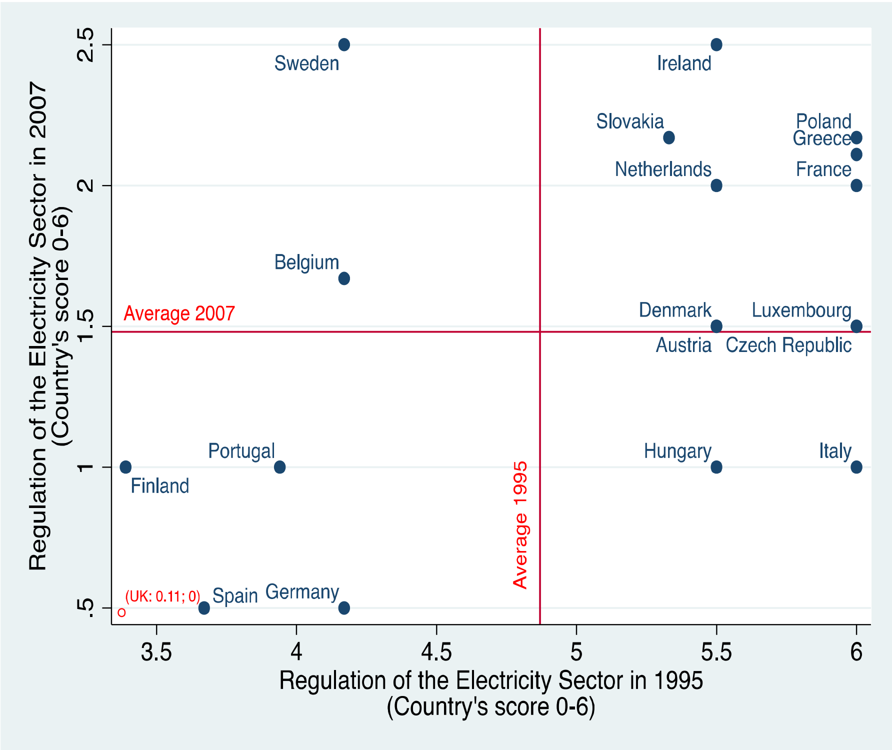


Figure 1 Changes in the regulation of the electricity sector between 1995 and 2007

Performances are also mixed in the other two groups; TFP growth in Belgium, a country which experienced only moderate deregulation, was good, even though it was not exactly as good as in Luxembourg and Denmark, namely countries where deregulation was more important (figure 2, panel C and D).

Conversely, in Sweden the situation does not seem worse than that of Italy, Hungary, the Czech Republic and Austria, that are countries belonging to the opposite group.

Lastly, table 4 reports a complete set of descriptive statistics referring to all the variables used in the econometric analysis. We deal with a total of 247 observations, namely we have 19 panels (sector-countries) times of 13 years (annual variations of the TFP), and the panel data set is strongly balanced. The magnitude of the *between standard deviation* is important both in regulatory indicators and in control variables; it means that the unobserved individual effects matter. The last two columns of table 5 are dedicated to the results of a panel unit root test, performed for all variables. P-values indicate that all the series we used are stationary.

Table 3 Changes in the low-level indicators of regulation in the electricity sector

	Entry Regulation		Public Ownership		Vertical Integration	
Country	1995	2007	1995	2007	1995	2007
Austria	6.00	0.00	4.50	4.50	6.00	0.00
Belgium	5.00	2.00	1.50	1.50	6.00	1.50
Czech Republic	6.00	0.00	6.00	4.50	6.00	0.00
Denmark	6.00	0.00	4.50	4.50	6.00	0.00
Finland	2.67	0.00	4.50	3.00	3.00	0.00
France	6.00	0.00	6.00	4.50	6.00	1.50
Germany	5.00	0.00	3.00	0.00	4.50	1.50
Greece	6.00	0.33	6.00	4.50	6.00	1.50
Hungary	6.00	0.00	6.00	3.00	4.50	0.00
Ireland	6.00	0.00	6.00	6.00	4.50	1.50
Italy	6.00	0.00	6.00	3.00	6.00	0.00
Luxembourg	6.00	0.00	6.00	3.00	6.00	1.50
Netherlands	6.00	0.00	6.00	6.00	4.50	0.00
Poland	6.00	2.00	6.00	4.50	6.00	0.00
Portugal	4.33	0.00	4.50	3.00	3.00	0.00
Slovakia	4.00	2.00	6.00	4.50	6.00	0.00
Spain	5.00	0.00	3.00	1.50	3.00	0.00
Sweden	5.00	0.00	6.00	6.00	1.50	1.50
United Kingdom	0.33	0.00	0.00	0.00	0.00	0.00

Source: OECD, Conway and Nicoletti, 2006

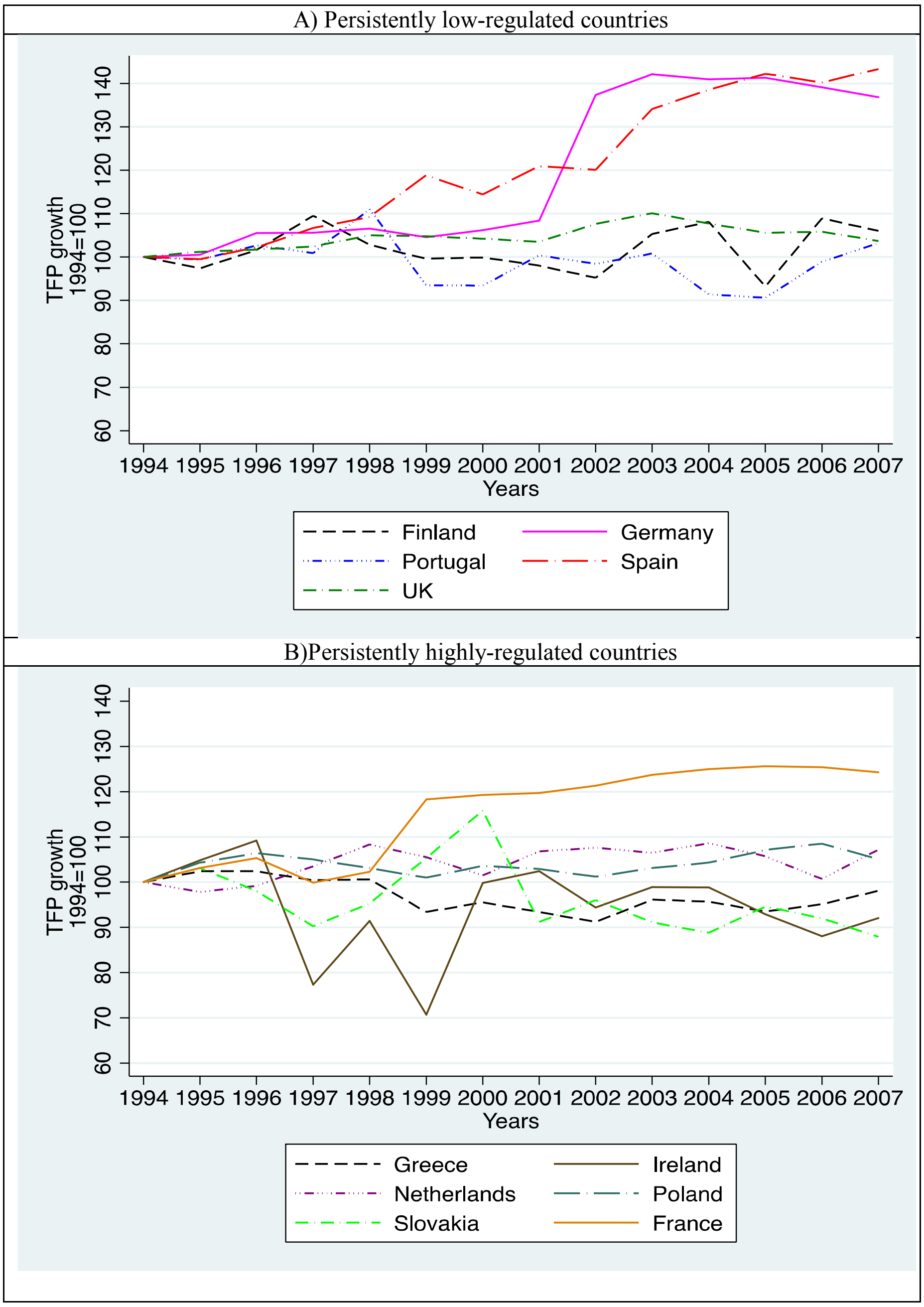
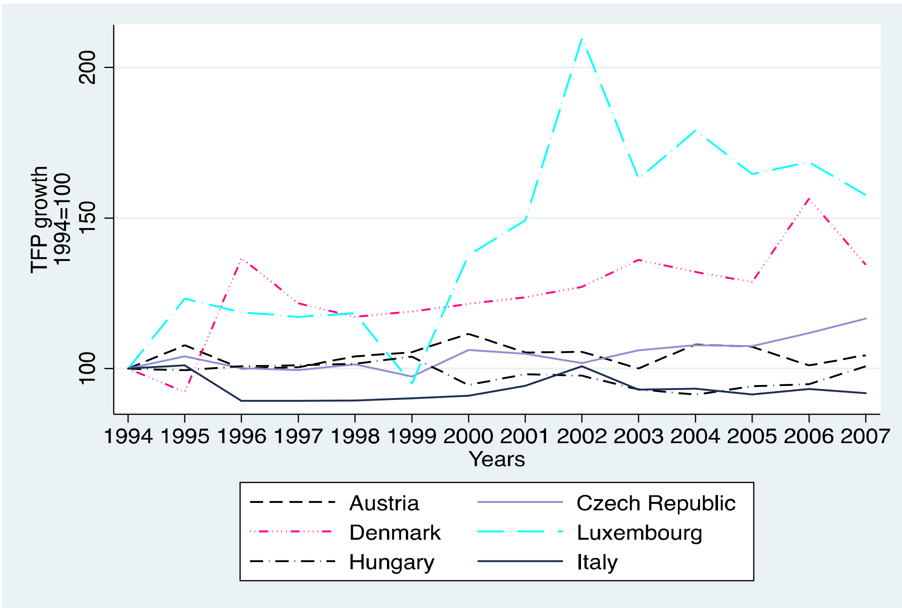


Figure 2 Cumulative Malmquist TFP growth index in countries organized by different changes in the regulation of the electricity sector

C) Countries with important deregulation



D) Countries with moderate deregulation

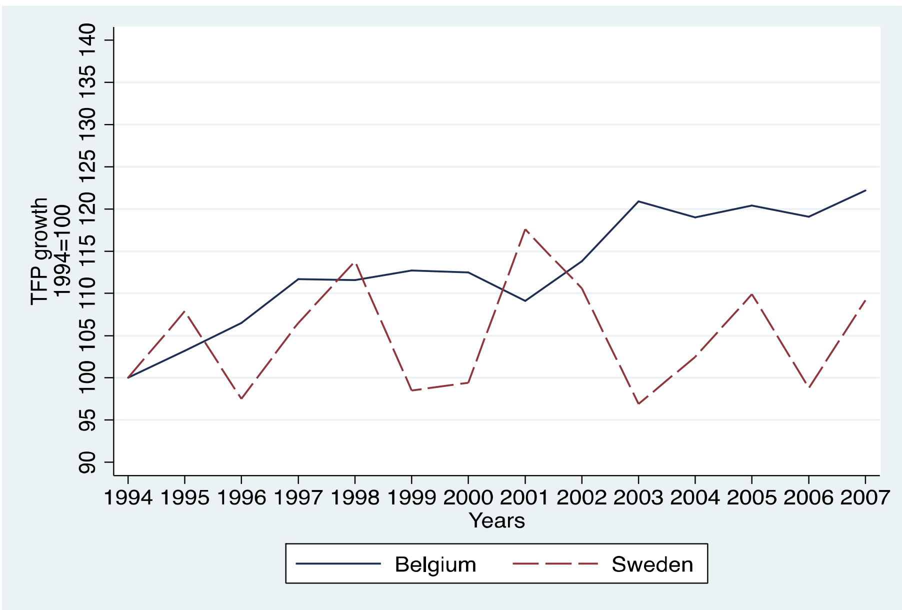


Figure 2 *(Continued)* Cumulative Malmquist TFP growth index in countries organized by different changes in the regulation of the electricity sector

4.3 Estimation results of the dynamic panel data analysis

Before discussing the results of the baseline specification reported in table 5, underlining some advantages and flaws of the econometric method we used is useful. First of all, autoregressive models confirmed the importance of the lagged dependent variable; it resulted always to be significant with a negative sign, and justifies to resorting to the dynamic panel data method[6].

In other terms, we were able to model a convergence process in which higher variations in period t-1 favor lower variations of the TFP in the next period. This outcome is coherent with what has been found in previous studies (Nakano and Managi, 2008). Using the GMM-dif estimator and lagged dependent variable forced us to lose two time periods, hence our observations were reduced from 247 to 209. All endogenous and predetermined variables were internally instrumented with lags 3 and longer.

We controlled for heteroskedasticity by implementing a robust GMM-dif estimator in the one step procedure. We also controlled for the instrument validity with both the Sargan test and the Arellano-Bond test for autocorrelations in residual differences. The latter resulted particularly useful, since the Sargan test was very often strongly weakened by the excessive number of instruments. Unfortunately, the advantage of controlling for endogeneity is offset by the high number of instruments. For this reason we also reported besides the observation number, the number of used instruments.

In any case, we performed several robustness checks by reducing and augmenting the number of instruments in each regression and the results remained quite stable[7].

Table 5 shows five different regressions in which the impact of the overall regulation of the electricity sector (REGEL) on TFP growth is always negative and significant. According to the empirical literature of the last years, the more stringent is regulation, the lower is TFP growth. More precisely, in our case a variation of one point in the OECD regulatory index produces a reduction between 0.020 and 0.021 in the Malmquist index, that is -2% in the TFP annual growth rate.

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[6] We performed autoregressive models both for the baseline specification and for the low-level indicators regressions and used three different estimators: OLS, fixed effect and GMM. Results are available on request.

[7] These estimations are available on request.

The lagged dependent variable is strongly significant with a negative sign and indicates the importance of taking into account adjustment processes when a dynamic relation between institutions and technical efficiency is analyzed. Although we corrected all the control variables for endogeneity, only the proxy of renewable sources technology (RENEN) came out as significant; the increase of the fraction of one percentage point in the electricity generated by green technologies improves the TFP growth by 0.4%. Apparently, the p-values in the Sargan test support the hypothesis of joint validity of instruments, even tough they appear too high. According to Roodman (2009), it is probably the case that the high number of instruments makes the Sargan test invalid. However, the Arellano-Bond test for autocorrelation seems to be a valid alternative; it informs us that the instruments we used were valid. Indeed, the econometric theory (Arellano, 2003, Roodman, 2009) tell us that first-order autocorrelation in differences is allowed because the idiosyncratic errors are serially correlated, whereas that of second-order one is not. This expected result is confirmed in our case.

Inference on the coefficient of the overall regulatory index (REGEL) shows that it is always significant, as mentioned, but in three regressions out of five the level of significance is only 10%. This weak significance leads us to conjecture that probably the overall result hides a complex picture of relationships between the components of both the Malmquist index of TFP and REGEL.

Tables 6, 7 and 8 report three models in which we regressed each component of the TFP change on the three components of REGEL. In all these specifications we detected second-order autocorrelation in differences, hence we modeled an MA(1) error term as in equations 5, 6 and 7.

On the whole, we can observe the absence of a unidirectional and sharp impact when we decompose the dependent and explanatory variables as mentioned above. For example, table 6 shows that only entry regulation has a negative and significant impact on the shift in the technological efficient frontier. As we hypothesized in section 2 (H2), entry barriers hinder the technological competition between incumbents and new entrants, hence the pace of technological change is slower.

Table 4 Descriptive statistics for variables used in the econometric analysis

Variable	Observations			Panel Stats	Mean	Std. Dev.	Min	Max	Levin-Lin-Chu Test for Panel Unit Roots	
									t-star	p-Value
Malmquist Index (TFPch)	Total	=	247	overall	1.01	0.10	0.53	1.60	6.08	0.98
	Panels	=	19	between		0.01	0.99	1.04		
	Years	=	13	within		0.10	0.50	1.57		
Malmquist Index Components:										
Technological Change (TECHch)	Total	=	*247*	*overall*	*1.00*	*0.10*	*0.68*	*1.60*	*5.72*	*0.97*
	Panels	=	*19*	*between*		*0.01*	*0.99*	*1.04*		
	Years	=	*13*	*within*		*0.10*	*0.65*	*1.52*		
Pure Efficiency Change (PEch)	Total	=	*247*	*overall*	*1.01*	*0.08*	*0.73*	*1.53*	*6.00*	*0.98*
	Panels	=	*19*	*between*		*0.01*	*0.98*	*1.03*		
	Years	=	*13*	*within*		*0.08*	*0.70*	*1.51*		
Scale Efficiency Change (SEch)	Total	=	*247*	*overall*	*1.00*	*0.07*	*0.78*	*1.47*	*5.21*	*0.97*
	Panels	=	*19*	*between*		*0.01*	*0.99*	*1.02*		
	Years	=	*13*	*within*		*0.07*	*0.77*	*1.47*		
Overall Regulation of Electricity Sector (REGEL)	Total	=	247	overall	3.045	1.781	*0.00*	*6.00*	2.53	0.99
	Panels	=	19	between		1.15	0.02	4.26		
	Years	=	13	within		1.39	0.49	5.59		
Regulation Sub-Indicators:										
Regulation of Entry (ENTRY)	*Total*	=	*247*	*overall*	*2.35*	*2.34*	*0.00*	*6.00*	*3.46*	*0.99*
	Panels	=	*19*	*between*		*1.16*	*0.08*	*3.59*		
	Years	=	*13*	*within*		*2.049*	*-1.16*	*6.97*		
Public Ownership PUBLIC	*Total*	=	*247*	*overall*	*4.07*	*1.96*	*0.00*	*6.00*	*-1.08*	*0.14*
	Panels	=	*19*	*between*		*1.87*	*0*	*6*		
	Years	=	*13*	*within*		*0.70*	*2.34*	*6.84*		
Vertical Integration VERTICAL	*Total*	=	*247*	*overall*	*2.71*	*2.19*	*0.00*	*6.00*	*3.40*	*0.99*
	Panels	=	*19*	*between*		*1.16*	*0.00*	*4.38*		
	Years	=	*13*	*within*		*1.870*	*-1.33*	*6.401*		
R&D intensity (%) (RD)	Total	=	247	overall	0.95	0.93	0.02	4.05	2.19	0.99
	Panels	=	19	between		0.86	0.06	2.98		
	Years	=	13	within		0.41	0.02	3.63		
Share of Electricity produced by CHP (%)	Total	=	247	overall	25.53	28.88	0.00	98.00	-0.87	0.19
	Panels	=	19	between		28.37	2.38	97.23		
	Years	=	13	within		8.27	-6.08	56.91		
Share of Electricity produced by Renewable Sources (%) (RENEN)	Total	=	247	overall	15.38	16.84	0.70	72.40	-1.13	0.13
	Panels	=	19	between		16.89	1.72	64.23		
	Years	=	13	within		3.49	1.59	29.89		

Conversely, vertical integration and public ownership do not seem to play any role in technological change. As regards the explanation of catching up (pure efficiency change), table 7 inform us that only vertical integration matters. In particular, our results support the idea that unbundling probably favors the corporate coherence and specialization of

companies (Teece and Rumelt, 1994), or helps to built a context in which more competition among fuel input suppliers emerges (Newbery, 1997). This condition could foster better quality provisions of fuels, and indirectly improves the efficiency of power plants.

Table 5 Effects of stringency of the overall regulation for electricity sector on the annual TFP growth rate (GMM-dif estimations)

	a	*b*	*c*	*d*	*e*
Dependent Variable	TFPch	TFPch	TFPch	TFPch	TFPch
Covariates					
Lagged TFPch	-0.390***	-0.397***	-0.396***	-0.397***	-0.396***
	(0.046)	*(0.045)*	*(0.039)*	*(0.046)*	*(0.036)*
REGEL	-0.020**	-0.020*	-0.020*	-0.021*	-0.020**
	(0.010)	*(0.011)*	*(0.011)*	*(0.011)*	*(0.010)*
Lagged RD	0.005	0.004	-0.003		
	(0.012)	*(0.011)*	*(0.011)*		
RENEN		0.004**	0.004*	0.004**	
		(0.002)	*(0.002)*	*(0.002)*	
CHP			-0.045		-0.108
			(0.198)		*(0.177)*
Time Dummies	*yes*	*yes*	*yes*	*yes*	*yes*
Obs	209	209	209	209	209
Instruments	104	109	112	109	109
Wald chi2	2721.22	3353.45	3699.38	3233.57	3709.26
Prob>chi2	0.000	0.000	0.000	0.000	0.000
AB Test H0: no autocorrelation					
AR(1) p-values	*0.025*	*0.033*	*0.037*	*0.034*	*0.032*
AR(2) p-values	*0.933*	*0.947*	*0.920*	*0.939*	*0.930*
Sargan Test p-values	0.998	0.999	1	0.999	0.999

Note: *Significant at the 10% level, **significant at the 5% level, ***significant at the 1% level. Robust standard errors are in parentheses. The table shows the results of the Arellano-Bond onestep estimators with the exception of the Sargan test of overidentifying moment conditions, that has been performed after a twostep procedure. The model specification takes into account endogeneity by inserting all covariates, but time dummies, as predetermined variables.

Table 8 shows an interesting result that seems to boost the level of overall regulation in the opposite direction with respect to what we found in the previous outcomes. First of all, it seems that to reach the optimal scale of operations (scale efficiency change) only the level of public ownership in the electric companies is important. Indeed, the coefficient of public ownership is strongly significant and positive, whereas other low-level indicators of regulation are not. This means that the higher the importance of public ownership, the higher the scale efficiency change. More precisely, a one point increase in the public ownership score, causes a 4% increase in

the growth rate of this TFP component. Thus, the H3 hypothesis is confirmed, according to which public companies probably better guarantee not simply the optimal scale of operations, but also the goal setting in those cases where more risky and longer term investments are required.

Eventually, from tables 6, 7 and 8 we draw conclusions regarding the absence of a strong negative and univocal influence of the overall regulation indicator on TFP productivity change. In fact, only one component of overall regulation at a time, significantly affects the three components of TFP. In addition, we found institutional settings that boost productivity in different directions, since higher levels of entry regulation and vertical integration depress productivity growth, while higher levels of public ownership seem to foster it. Thus, policy makers should pay more attention to these different effects of the various regulation aspects.

5. Conclusions

In this study we investigated the relationship between the stringency of regulation and total factor productivity growth of the electricity sectors in 19 EU countries. Its main purpose was to highlight the incentives to use inputs better and to introduce technological innovation, created because of the diminishing levels of regulation.

By analyzing this relationship in a descriptive manner, a clear picture does not emerge. For example, the cumulative TFP growth index is important not only in the persistently low-regulated countries (according to the OECD indicator), such as Germany and Spain, but also in a persistent high-regulated country like France. These first results led us to conjecture the existence of no-unidirectional forces beyond the overall regulation of the electricity sector. Hence, in the econometric analysis we decomposed both TFP index and the overall OECD regulatory indicator. According to the recent literature focused on this theme, we found a negative and significant effect of the overall regulation on TFP growth, even though the significance level of the coefficients is very often weak (10% level).

After the analysis of the components of TFP growth and the regulatory indicator, the hypothesis relating to the existence of no-unidirectional forces is confirmed. Indeed, the estimation results tell us that only stringency in entry regulation significantly reduces technological change, whereas both vertical integration and public ownership do not seem to play any role in this source of growth. Thus, according to the neo-Schumpeterian theories, new entrants and their radical innovations are crucial in the process of creative destruction. Likewise, if we consider the catching up process (pure efficiency change), it is only vertical integration

that exhibits a negative and significant impact on the former. According to the Newbery's view, vertical integration is the best way to create and protect rents for distribution to the incumbent interest groups, i.e. the high cost domestic fuel producers. When these suppliers are protected, technical inefficiency raises in the generation segment.

Lastly, we found an interesting result concerning the explanatory variables of the scale efficiency change; in this case only public ownership matters, in other terms high degree of public ownership of electric companies guarantee improvements in reaching the optimal scale of production. This evidence finds support in the following crucial issues: climate change and related policies impose significant new investment requirements on the power sector. More precisely, investments in alternative low fossil fuel technologies expose investors to many risks, especially when the payback periods for these investments are long (20-30 years). Like during the electrification period in the early Twentieth Century, public ownership could be the best solution to insure the large scale investments that the electricity sector requires in this new era.

Table 6 Effects of Entry Regulation, Public Ownership and Vertical Integration on Technological Change (GMM-dif estimations)

Dependent Variable	TECHch a	TECHch b	TECHch c	TECHch d	TECHch e	TECHch f	TECHch g	TECHch h	TECHch i
Covariates									
TECHch_1	-0.418***	-0.276***	-0.417***	-0.438***	-0.319***	-0.424***	-0.525***	-0.275***	-0.387***
	(0.085)	(0.064)	(0.089)	(0.096)	(0.052)	(0.108)	(0.134)	(0.067)	(0.080)
ENTRY	-0.040**	-0.037*	-0.048***						
	(0.016)	(0.019)	(0.018)						
PUBLIC				-0.052	-0.031	-0.020			
				(0.037)	(0.024)	(0.023)			
VERTICAL							-0.026	-0.000	-0.004
							(0.025)	(0.011)	(0.014)
RD_1	0.049			0.025			0.126*		
	(0.050)			(0.031)			(0.068)		
RENEN		0.011			0.011			0.01	
		(0.007)			(0.007)			(0.007)	
CHP			0.532			0.493			0.926
			(0.413)			(0.468)			(0.659)
Time Dummies	yes	yes	yes	yes	yes	yes	yes	yes	yes
Obs	209	209	209	209	209	209	209	209	209
Instruments	46	56	46	46	56	56	26	53	39
Wald chi2	3691.37	1725.518	2153.203	4059.632	9490.787	4071.432	3732.978	16226.624	4647.296
Prob>chi2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
AB Test H0: no autocorrelation									
AR(1) p-values	0.303	0.068	0.243	0.290	0.071	0.296	0.416	0.040	0.222
AR(2) p-values	0.013	0.082	0.009	0.022	0.098	0.011	0.040	0.151	0.018
AR(3) p-values	0.279	0.286	0.319	0.329	0.357	0.382	0.424	0.336	0.471
Sargan Test p-values	0.999	1.000	1.000	0.993	1.000	1.000	0.820	1.000	0.999

Note: *Significant at the 10% level, **significant at the 5% level, ***significant at the 1% level.
Robust standard errors are in parentheses. This table shows the results of the Arellano-Bond onestep estimators with the exception of the Sargan test of overidentifying moment conditions, that was performed after a twostep procedure. The model specification takes into account endogeneity by inserting all covariates, except Time Dummies, as predetermined variables. The model also fits with the MA(1) correlation in the idiosyncratic errors.

Table 7 Effects of Entry Regulation, Public Ownership and Vertical Integration on the Catching Up (pure efficiency change) (GMM-dif estimations)

Dependent Variable	PEch a	PEch b	PEch c	PEch d	PEch e	PEch f	PEch g	PEch h	PEch i
Covariates									
PEch_1	-0.723***	-0.692***	-0.707***	-0.721***	-1.017***	-0.740***	-0.798***	-0.820***	-0.757***
	(0.149)	(0.140)	(0.137)	(0.170)	(0.200)	(0.162)	(0.129)	(0.120)	(0.120)
ENTRY	-0.031	-0.024	-0.026						
	(0.030)	(0.022)	(0.024)						
PUBLIC				0.027	0.138	0.09			
				(0.038)	(0.319)	(0.062)			
VERTICAL							-0.055**	-0.056**	-0.053**
							(0.023)	(0.023)	(0.021)
RD_1	0.033			0.008			0.015		
	(0.025)			(0.027)			(0.022)		
RENEN		0.002			0.008			0.004	
		(0.005)			(0.006)			(0.005)	
CHP			0.091			0.341			0.279
			(0.882)			(0.939)			(0.878)
Time Dummies	yes	yes	yes	yes	yes	yes	yes	yes	yes
Obs	209	209	209	209	209	209	209	209	209
Instruments	46	56	56	46	24	34	43	39	39
Wald chi2	572.914	412.833	1019.796	1196.937	844.797	426.786	1574.567	527.857	914.736
Prob>chi2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
AB Test H0: no autocorrelation									
AR(1) p-values	0.035	0.024	0.007	0.022	0.047	0.045	0.007	0.003	0.002
AR(2) p-values	0.013	0.012	0.020	0.018	0.050	0.020	0.035	0.028	0.042
AR(3) p-values	0.168	0.147	0.164	0.110	0.163	0.201	0.140	0.128	0.110
Sargan Test p-values	1.000	1.000	1.000	1.000	0.669	0.999	1.000	0.999	0.995

Note: *Significant at the 10% level, **significant at the 5% level, ***significant at the 1% level.

Robust standard errors are in parentheses. This table shows the results of the Arellano-Bond onestep estimators with the exception of the Sargan test of overidentifying moment conditions, that was performed after a twostep procedure. The model specification takes into account endogeneity by inserting all covariates, except Time Dummies, as predetermined variables. The model also fits with the MA(1) correlation in the idiosyncratic errors.

Table 8 Effects of Entry Regulation, Public Ownership and Vertical Integration on the Scale Efficiency Change (GMM-dif estimations)

Dependent Variable	SEch a	SEch b	SEch c	SEch d	SEch e	SEch f	SEch g	SEch h	SEch i
Covariates									
SEch_1	-0.390***	-0.395***	-0.393***	-0.371***	-0.379***	-0.369***	-0.398***	-0.405***	-0.399***
	(0.093)	(0.092)	(0.090)	(0.076)	(0.070)	(0.073)	(0.088)	(0.085)	(0.088)
ENTRY	0.004	0.006	0.004						
	(0.006)	(0.007)	(0.007)						
PUBLIC				0.042***	0.049***	0.043***			
				(0.008)	(0.013)	(0.008)			
VERTICAL							0.004	0.006	0.005
							(0.005)	(0.004)	(0.005)
RD_1	0.02			0.003			0.019		
	(0.024)			(0.023)			(0.022)		
RENEN		-0.001			-0.007*			-0.002	
		(0.004)			(0.003)			(0.003)	
CHP			-0.091			-0.117			-0.104
			(0.186)			(0.083)			(0.187)
Time Dummies	yes	yes	yes	yes	yes	yes	yes	yes	yes
Obs	209	209	209	209	209	209	209	209	209
Instruments	66	66	66	66	66	66	73	66	66
Wald chi2	2196.948	473.764	853.573	1486.025	2652.102	1581.654	1576.555	1109.842	1790.514
Prob>chi2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
AB Test H0: no autocorrelation									
AR(1) p-values	0.005	0.011	0.009	0.017	0.013	0.018	0.006	0.011	0.010
AR(2) p-values	0.005	0.005	0.006	0.008	0.004	0.007	0.003	0.003	0.005
AR(3) p-values	0.515	0.487	0.508	0.487	0.523	0.490	0.526	0.502	0.515
Sargan Test p-values	1.000	1.000	1.000	1.000	1.000	0.981	1.000	1.000	1.000

*Note: *Significant at the 10% level, **significant at the 5% level, ***significant at the 1% level.*

Robust standard errors are in parentheses. This table shows the results of the Arellano-Bond onestep estimators with the exception of the Sargan test of overidentifying moment conditions, that was performed after a twostep procedure. The model specification takes into account endogeneity by inserting all covariates, except Time Dummies, as predetermined variables. The model also fits with the MA(1) correlation in the idiosyncratic errors.

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