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## The Impact of the Regulatory Reform Process on R&D Investment of European Electricity Utilities

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# THE IMPACT OF THE REGULATORY REFORM PROCESS ON R&D INVESTMENT OF EUROPEAN ELECTRICITY UTILITIES\*

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## **ABSTRACT:**

The aim of this paper is to give deeper insights into the impact of regulatory reforms and privatization on R&D spending of electricity utilities. Building on a panel data set including the biggest European utilities from eight EU-countries over a period from 1985 until 2010, we find a strong negative influence of privatization and also a negative overall impact of regulation on R&D investment. Nearing competition has a dampening effect on R&D spending, but once the market and regulatory framework conditions have been established, higher levels of competition positively influence R&D. Our results further indicate that the relation between competition and innovative investment can be described as inverted U-shaped. Finally, we could not find any evidence that (ownership) unbundling and incentive regulation affect R&D expenditures of the utilities.

**KEYWORDS:** Electricity sector, R&D spending, regulatory reforms, liberalization, competition, privatization

**JEL classification:** L43, L51, L94

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## 1. Introduction

During the last two decades the European electricity sector has changed radically. The first internal electricity directive 96/92/EC concerning common rules for the internal electricity market, which entered into force in February 1997, forced EU member states to start liberalization of their electricity industries and to open up their markets for competition gradually. Third party access to the electricity grid became mandatory and accounting unbundling of the transmission grid and other stages of the sector had to be implemented. The second directive 2003/54/EC and the third directive 2009/72/EC should further spur the achievement of a harmonized and liberalized EU-wide electricity market. During that period, regulation altered and adapted to these changes, and moreover, privatization of the formerly state owned utilities took place all across Europe. Contrary to the EU directives, which were enacted on European level, privatization was only a question of national governments and parliaments. Although the direction of all these reforms was more or less predetermined, there were differences in the speed of the reform implementation between member states; in terms of the degree of public ownership there are still big differences between countries today.

Initially, politicians and regulators concentrated on building up a functioning regulatory regime. Their primary focus was on static (allocative) efficiency, i.e. prices should be set close to marginal costs. This should be achieved through the introduction of market mechanisms, regulated grid tariffs and efficiency gains, which would ultimately lead to lower costs and prices, and thereby to a higher level of social welfare. With the change from cost-based regulation regimes to more incentive-based forms of regulation such as price or revenue caps, the question arose if under these regimes enough attention is given to investment incentives and thereby to dynamic efficiency (Brunekreeft and Bauknecht 2009). Today's few discussions on that topic tend to focus on the effects on capital investment (Gugler et al. 2011, Alesina et al. 2005, Newbery 2005, von Hirschhausen et al. 2004), while even less attention has been given to innovation, and research and development (R&D) investment (Jamash and Pollitt 2008, Munari 2003). A very topical exception is the work of Kim et al. (2012), who look at R&D expenditures of electricity-generating firms in OECD countries.<sup>1</sup>

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<sup>1</sup> Contrary to Kim et al. (2012) the paper in hand focuses only on the specific regulatory reform process and circumstances in Europe, which differ in many aspects from the situation in other countries. Another study that analyzes the impact of regulation on innovation in the European electricity sector is Kucsera and Schmitt (2012), focusing on patent activity.

All across Europe the major electricity companies have drastically reduced R&D expenditures since the late 1990s, as illustrated in Figure 1 or in Sterlacchini (2010).<sup>2</sup> Simultaneously, R&D productivity has increased, at least with regard to short-term projects (Jamash and Pollitt 2008, Munari et al. 2002). This brings us to the question if this drop in R&D spending is problematic from a welfare economic perspective or if it could be compensated through higher levels of productivity? Several arguments point into the direction of the former, meaning that this reduction in R&D is, indeed, a problem. First of all, it is highly questionable if firms' increased R&D productivity also holds for long-term R&D projects (Munari 2003). Strongly related to the first argument is the second, after which the relation between research inputs, such as firm R&D spending, and innovative outputs, as for instance the number or the quality of patents, is typically positive (Kamien and Schwartz 1975). Third, as R&D investments of the electrical equipment manufacturers do not increase considerably or even fall as well (Sanyal and Ghosh 2010, Jamash and Pollitt 2008), they cannot compensate for the decline in the utilities' R&D expenditures. Furthermore, according to Sanyal and Cohen (2009), electrical equipment suppliers need collaboration with electricity utilities in order to test and to improve their technologies. If utilities reduce their R&D efforts, this can negatively affect the investment incentives of electrical equipment suppliers, which can further delay the creation and adoption of new or improved technologies. Therefore, total investment in the electricity industry decreases if the government is not stepping in, which is not the case in Europe.<sup>3</sup> Finally, the electricity industry is faced with increasing challenges, which require more instead of less innovation. Global warming, the reduction of emissions, the finiteness of fossil fuels and not least rapidly changed energy policies caused by the Fukushima catastrophe are only a few examples. It is often claimed that innovation may be the solution to deliver the necessary technological progress, but can innovation provide the right outcomes when R&D spending of the utilities has dropped so dramatically?

This paper tries to identify the reasons for the drop in European utilities' R&D expenditures. In particular, we want to find out whether different measures of the regulatory reform process, the anticipation of liberalization, increased levels of competition or privatization contributed to this steep decline? In order to deal with this research question empirically, we build our

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<sup>2</sup> This sharp decline is not only restricted to European firms. During the time period 1993-2000 total R&D spending of electric utilities in the US dropped by nearly 74% (Sanyal and Cohen 2009). The authors further conclude that this decline cannot be explained through any general macroeconomic factor, as other industries experienced increasing levels of R&D expenditures during that time period.

<sup>3</sup> In fact, public R&D spending in the European countries dropped substantially during the last two decades (Kucsera and Schmitt 2012). Moreover, Dooley (1998) reports that the linkage between public and private sector R&D investment in the energy market is positive.

analysis on a panel data set including the main utilities in eight European countries over the period from 1985 until 2010.

This paper is organized into six sections. Section two provides background information on R&D in the electricity sector. Section three presents our main hypothesis and the corresponding literature. Section four describes the data set, section five illustrates our econometric model specification, main results and robustness checks. The last section concludes.

## **2. R&D in the electricity industry**

R&D is essential for the innovative process in an economy and, unquestionably, it is an important driver of economic growth. Thereby it plays an important role as determinant of economic welfare (Bond and van Reenen 2007). Typically, R&D projects can be described as long-term, risky, unpredictable, multi-stage, labor intensive and idiosyncratic (i.e. not easily comparable to other projects) (Holmstrom 1989). There are different economic characteristics that distinguish R&D investment of a firm from other kinds of investment. First, uncertainties arising from R&D activities are relatively high, since R&D outcomes are more difficult to predict and to evaluate in comparison to other outcomes of a firm. Second, incomplete property rights play an important role (Cohen and Sanyal 2004). Successful R&D in the energy sector – which frequently leads to the occurrence of public goods – produces knowledge that is not easy to fully protect. This kind of market failure cannot be completely solved through patent systems, which bring along additional problems. Therefore, free riding can be a serious issue in this context, ultimately leading to lower levels of R&D investment than would be socially optimal. Third, the indivisibility of R&D projects can hamper investment, in particular for research, which addresses the interaction between different stages of an industry that are not part of a single vertically-integrated company. This is especially true for the electricity sector with its four different stages generation, transmission, distribution, and retail (Defeuilley and Furtado 2000). Still, most R&D in the electricity sector is performed at the generation stage, but R&D in transmission, distribution, and especially in the overlap between the different stages is becoming more important. Reasons are for instance the increasing importance of smart grids, e-mobility, decentralized generation and demand side management programs.

The influence of the government on the electricity sector is still high in comparison to other industries. Although privatization has gradually reduced direct state influence on most European utilities, politicians have achieved more indirect influence through regulation. Therefore,

firm behavior in the electricity sector has often to be seen in the light of government decisions, which sometimes are not easy to anticipate. Firms always have to fear political and regulatory reforms, which increase uncertainty and which can be costly especially in case of long-term decisions (Joskow 2002).<sup>4</sup> As R&D projects are rather long-term orientated, they are particularly sensitive to political and regulatory changes.

### **3. Literature and hypotheses**

We differentiate between three different groups of factors that potentially determine utilities R&D investment in the electricity sector, namely firm specific, market specific and political determinants (including regulatory and ownership measures). In this section these factors will be described in detail and a comprehensive discussion of the relevant literature will be provided. From this we derive our hypotheses for the empirical analysis. Within this work, we adopt an industrial organization perspective with regard to innovation and R&D, and our main focus is directed towards the impact of (expected) competitive pressure, regulation and privatization on firm R&D spending. Since the literature on this topic is rather limited, which is in particular true for Europe, we extend our focus also on other industries and countries if it seems reasonable.

#### **3.1 Firm specific determinants of R&D investment**

Different firm specific factors can have a substantial impact on R&D expenditures of electric utilities. Firm size plays a key role here, as larger firms usually perform more R&D than smaller ones. The reason is that a given cost reduction caused by process innovation results in higher savings of a firm, when it is applied to a larger quantity. Jamasb and Pollitt (2008) summarize several empirical studies about the electricity sector, which altogether come to the conclusion that reduced firm size has a negative effect on R&D investment. Firm size increases the likelihood of investing in R&D and it has a positive effect on the absolute amount invested. *In summary, we expect to find a positive impact of firm size (measured by sales) on R&D spending of electric utilities.*

Firm specific financial factors such as the leverage ratio or free cash flow can also influence R&D spending. On average, leverage of the major European utilities has increased after the

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<sup>4</sup> This situation is often described as a “(regulatory) commitment” problem, which according to Laffont and Tirole (1993) can be illustrated in a principal-agent-problem setting. If politicians/regulators (the principal) change framework conditions after the utility (the agent) has taken a decision, the agent will typically suffer from these changes, as he could not take them into account when deciding at the beginning. Anticipating the incentives of the principal the agent will rather behave differently.

mid 1990s out of different reasons. First, the start of the liberalization and privatization processes induced a wave of mergers and acquisitions (M&A) within and between countries, which frequently have been financed by higher levels of debt (Jamasp and Pollitt 2008). Second, since most of the former state-owned utilities have been (at least partly) privatized, they had to subsequently increase their leverage levels in order to meet the equity debt ratio required by the capital markets. Finally, higher leverage can be used strategically by private utilities to induce regulators to approve higher prices (Bortolotti et al. 2011). Unquestionably, permanently elevated leverage ratios lead to greater financial risk and to more constrained resources within a company, which raises the question if this affects risky R&D investment. Indeed, several studies find that there is a negative effect, as e.g. Cassiman et al. (2005) examining 31 M&As, Cumming and Macintosh (2000) studying the Canadian biotechnology industry or Hall (1990) analyzing US manufacturing industries.

Beside the financial constraint caused by a high leverage rate, the level of free cash flow can also be a determinant of R&D spending. Simply speaking, a higher level of cash flow may lead to more R&D spending, as financial constraints and competition for funds get softer. Empirical evidence on this issue is ambiguous. In contrast to Hall (1992), who finds a positive causal relation between R&D and cash flow using a panel of large US manufacturing firms, Bond et al. (2005) cannot detect an effect of cash flow on R&D in their sample of British and German firms. *However, we include both financial factors – the leverage ratio and free cash flow – as control variables in our R&D investment specification. We anticipate a negative impact of the leverage ratio and a (weakly) positive impact of free cash flow on R&D spending.*

Finally, differences in generation technologies influence the incentives of electricity companies to perform R&D. Generators with a high share in hydro power generation have typically weak incentives to conduct research, as this technology has not experienced big technological innovations during the last decades and can be considered relatively stable (Cohen and Sanyal 2004). In contrast, the amount of R&D spending on nuclear power technology has traditionally been high (Jamasp and Pollitt 2008). Therefore, utilities with a high share in nuclear power generation should have even greater incentives to invest in nuclear-related R&D. *In our analysis we also incorporate the firm specific shares of hydro and nuclear power generation capacity relative to the total capacity in order to account for their specific impact on R&D spending. A priori we expect to observe a negative effect of hydro generation and a positive effect of nuclear generation on firm R&D expenditures.*

### 3.2 Market specific determinants of R&D investment

Market conditions such as the demand for electricity and the competitive situation in the sector can also be important determinants of R&D. Initially, two different hypotheses were used in the literature to explain the drivers of R&D spending: the demand-pull hypothesis and technology-push or supply-push hypothesis (Schmookler 1966; Scherer 1965, 1982). According to the former, increasing industry demand is primarily responsible for higher R&D spending of the firms, as risks associated with R&D projects get relatively smaller with rising demand (and thereby also higher profit expectations). The latter hypothesis states that R&D spending pushes technological progress, with the result of new innovations that improve the competitive situation of the firm, without considering whether this progress was previously demanded by customers. Empirical evidence shows that neither just demand side factors nor just supply side factors can explain the R&D behavior of the firms (Jaffe 1986, Scherer 1982). *In order to account for demand side factors we include the country-specific growth rate of electricity demand in our regressions. Supply side factors will be taken into account through firm- and time-fixed effects, and through the firm specific factors mentioned before.*

With regard to competition of a formerly monopolistic industry, one can distinguish between nearing competition and the actual level of competitive pressure. Nearing competition describes a situation, when due to a particular event the present incumbent and monopolist starts to fear future competition. The liberalization process in the European electricity sector, which enabled entrants to enter the market for the first time, is a good example for that. Anticipating liberalization of the sector, former incumbent utilities expect radically modified framework conditions with serious consequences for the market structure. The fear of finding themselves in such a situation unprepared for competition raises their uncertainty significantly, as overall risks increase. Sustained additional risk raises the cost of capital, which can have at least two consequences according to Blyth et al. (2011). First, investment can be delayed until uncertainty has been at least partially resolved. Second, the additional risk increases the payoffs required from the project in order to justify proceeding with the project rather than waiting. In any case, higher uncertainties and risks affect profit expectations negatively, which could be counteracted by operating more cost-efficiently. One practicable possibility for the firms to do so, would be the reduction of those kind of R&D investment, which is not directly linked to cost efficiency increasing process innovation.

The fear of nearing competition, caused by an event such as liberalization, does not necessarily say much about the existing level of competition on a market. The subsequent question is,



whether the actual competitive pressure among firms leads to more or to less investment in R&D. That there is no clear and easy answer to this question has not least been shown by Aghion et al. (2005), who describe the relation between competition and innovation as inverted U-shaped. Nevertheless, one can distinguish at least two conflicting lines of reasoning, which have particular relevance for the electricity industry. On the one hand, higher levels of competition can increase R&D spending either because of the incumbent or because of the entrants. With regard to the former more competition can increase the incentive of the incumbent to innovate and to spend more on R&D in order to “escape competition” (Aghion et al. 2005, Arrow 1962). However, this race for patents – implying more R&D efforts – can also be initiated by the entrant, who has to start from scratch, whereas the incumbent mainly has to replace himself and his older profits when he innovates (“replacement effect”) (Gilbert and Newbery 1982, Arrow 1962). As the importance of real entrants on the European electricity sector has been rather limited in recent years, we expect that this line of reasoning would primarily hold for the incumbents.

On the other hand, more intense competition can have a depressing effect on firms R&D spending. According to Motta (2004) and others, an increase in competition makes it more difficult for a firm to exclusively benefit from its innovations. In other words, more competition can increase free riding of competitors, finally reducing the appropriability of a firm to profit from its own inventions. This ultimately lowers the incentives of the underlying firm to innovate and to spent more resources on R&D.

Empirical evidence regarding this controversial issue is scarce in particular for the European energy market. Defeuilley and Furtado (2000) compare electricity reforms in the US and UK (England and Wales). According to the authors the introduction of competition has led to a lower level of firm R&D investment, but additionally the nature of investment has changed, as R&D efforts are now more focused on short-term objectives and concrete applications. Incentives for risky long-term research, and in particular for the kind of research that focuses on the interaction between generation, transmission and distribution, have dropped remarkably. Sanyal and Cohen (2009) analyze the impact of restructuring in the US electricity sector over the period from 1990-2000 and come to the conclusion that both, greater competition and nearing competition, affect firm R&D expenditures negatively.<sup>5</sup> *In order to deal with competition and to test for the conflicting lines of reasoning, we make use of the C1 market concen-*

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<sup>5</sup> The authors find that a 1 percent increase of customers eligible for retail competition (as a measure of actual competitive pressure) decreases R&D spending by 0.4 percent; and every month retail competition comes closer (as a measure for nearing competition) leads to an overall decline in utilities R&D investment of 3 percent.

*tration index as well as of a dummy variable accounting for the existence of a wholesale market. Nearing competition, for which we expect to find a negative impact on R&D investment, will be captured by third party access to the transmission grid and by different specifications.*

Finally, public R&D support such as tax incentives or direct R&D subsidies can affect the amount and the composition of utilities' R&D spending (Hall and van Reenen 2000). We econometrically capture those factors by firm- and time-fixed effects.

### **3.3 Political, regulatory and ownership determinants of R&D investment**

#### **3.3.1 Regulation**

One can differentiate between the overall impact of regulation on R&D investment and the impact of the specific regulatory measures on R&D investment. The former subsumes all regulatory actions taken by governments and regulators and, thereby, helps to get a general impression about the effect of regulation on utilities R&D expenditures. Unquestionable, the whole liberalization process in the European electricity sector has changed market processes and regulatory framework conditions from scratch. This has also affected the R&D spending of utilities, which came under the general pressure of cost reductions and which – not least because of its public goods characteristics – suffered in particular under rising uncertainty and the fear of competitive pressure (Dooley 1998). This holds primarily for particularly expensive long-term R&D projects that are not directed to cost reducing process innovation. *Therefore, we expect to find a negative impact of the European regulatory reform process on firm R&D spending in general.* The hypothesis is supported by Sanyal (2007) analyzing US utilities expenditures on environmental research during 1990 and 2001. According to the author, regulatory reforms,<sup>6</sup> which started in the year 1996, led to a drop of 40 percent in firms' R&D spending. Similar results were obtained by Sanyal and Cohen (2009), looking at US utilities' R&D expenditures.

As mentioned before, overall regulation can be decomposed into the specific individual measures of regulation, which could influence R&D investment differently. Therefore, we divide the literature into the subcategories entry regulation, vertical integration vs. unbundling, and incentive regulation vs. cost-based regulation of the power lines. Overall, the literature on the impact of regulation on R&D expenditures of utilities is very limited, especially for countries outside the US. In many respects the institutional and regulatory frameworks in

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<sup>6</sup> Sanyal (2007) denotes the regulatory reform process as deregulation, which is often the case in US studies.

Europe and in the US differ substantially, necessitating more research on this topic for Europe.

### **a) Market entry regulation**

The main purpose of access regulation is to reduce market entry barriers, to help entrants to enter the market, and finally, to increase the level of effective competition. In other words, entry regulation is strictly required for achieving competition in an industry that is characterized by natural monopoly characteristics. Policymakers and regulators can choose between different instruments of entry regulation. Since these instruments can differ substantially from each other, it is not unlikely that they affect firms in a different way.<sup>7</sup>

The first entry variable accounts for the existence of a liberalized wholesale market. Prior to liberalization, almost all electricity in Europe was generated by big vertically-integrated utilities, which usually retained their specific individual generation technologies over time. Especially since the last decade new generation technologies came up such as renewables, which are particularly interesting for entrants as they have to start their business from scratch, in contrast to incumbents who can still rely on their “old” generation power plants and technologies. Through the existence of a wholesale market, entrants are now able to sell their electricity to third parties in a much easier way. This attracts new investment in these technologies not only from the entrants but also from the incumbents, who do not want to lose their leading position at the technological front. In addition, there are policies in some European countries that favor “green” generation sources over traditional generation technologies. All in all, the existence of a wholesale market has helped to open up the electricity market for new innovations and technologies. Liberalized wholesale markets do not necessarily only attract more investment for renewables. This can also be true for the conventional technologies, as the incumbents can have the intention to “escape” competition, while entrants have to invest a lot in order to catch up. *In summary, we anticipate that the existence of a liberalized wholesale market has a boosting effect on R&D expenditures.*

The second variable is third party access to the transmission grid. Stepwise simplification of third party access should ensure that new generators get connected to the market such that they have access to the natural monopoly. Traditionally, this measure has been among the first ones to be implemented in EU member states according to the Directive 96/92/EC. Hence, a wholesale market could only be built up in a country, once third party access to the trans-

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<sup>7</sup> Some entry regulation measures, such as a minimum consumption threshold for consumers that want to switch their supplier, are not mentioned here, since they play a minor role as determinants of R&D expenditures.

mission grid had been possible (at least for the countries we consider here). Policy makers did not expect that the first step towards third party access would directly deliver competition into the market. Rather, free access to the market has been a precondition for occurrence of competition, as other regulatory measures such as effective unbundling (see section 3.3.1 b for more details) had to be implemented earlier. Therefore, third party access is a good indicator for nearing competition. As mentioned in section 3.2, the incumbents fear nearing competition, due to more uncertainties and higher risks (Blyth et al. 2008) and, thus, try to lower financial risks within the firm, which can be easily done by reducing R&D. Due to economies of scale of the former incumbents, it is likely that a reduction in their R&D spending outweighs a possible increase in entrants' R&D efforts, in particular on a short-term basis. Furthermore, as our data set primarily consists of former incumbents, *we expect to find a negative effect of third party access on firm R&D expenditures.*

#### **b) Vertical integration vs. unbundling**

Since the mid-nineties the degree of vertical integration has decreased continuously across European utilities, as was required by different EU directives. As a first step, functional and accounting unbundling of the transmission grid had been implemented, followed by the requirement of legal unbundling. With the third legislative package on European energy markets in September 2007, the European Commission required even stronger forms of unbundling, such as ownership unbundling, a deep independent system operator (ISO) or an independent transmission operator (ITO).<sup>8</sup> In recent years the focus of politicians and regulators regarding unbundling extended from the transmission grid to the distribution lines, although the level of unbundling of the distribution lines today is far behind the level of the transmission grid. Theoretical and empirical evidence on the consequences of unbundling are ambiguous. Possible positive effects of stronger forms of unbundling like increased competition and less discrimination potential against entrants should be compared to possible negative effects like the problem of double marginalization, the loss of coordination advantages, and the loss of vertical synergies between different stages of the sector.<sup>9</sup>

A number of arguments point into the direction that unbundling – and especially ownership unbundling as its strongest form – leads to lower levels of R&D spending of the utilities, at least in the short-run (Brunekreeft and Bauknecht 2009, Jamasb and Pollitt 2008). First, big-

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<sup>8</sup> Ownership unbundling is the strongest and most dominant form of unbundling in Europe. It requires that ownership and control of the transmission grid have to be fully separated from generation and distribution. For a detailed description of the less stringent ISO and ITO options, we refer to Balmert and Brunekreeft (2010).

<sup>9</sup> As this discussion is not the main focus of this work, we refer inter alia to Gugler et al. (2011), Arocena et al. (2009), Pollitt (2008), Keller and Wild (2004), and Kwoka (2002) for deeper insights.

ger firms normally perform more R&D, as risks of R&D projects get relatively smaller with increasing firm size (see section 3.1 for more details). Since ownership unbundling of former vertically-integrated utilities reduces firm size significantly, one can expect that the divestment of the grid assets reduces joint R&D spending of the old generation company and of the newly created grid company. This argument also holds for less strong forms of unbundling such as legal unbundling, but very likely to a lower extent. In addition, risk diversification of R&D projects is only possible for an integrated firm with its different stages, but not for a single generation or grid company. However, mergers between utilities could work in the opposite direction, leading to bigger entities in the long-run. Empirical evidence confirms that R&D spending of utilities increases with firm size (Delaney and Honeycutt 1976, Wilder and Stansell 1974).

Second, the problem of free riding can have a dampening effect on R&D investment. If there is only one vertically-integrated utility in a country, clearly all innovations comes from this firm. However, in a market with more firms (as a result of restructuring and unbundling) the utilities might have greater incentives to benefit from innovative outcomes of the others, leading to a reduction in their R&D budget. Third, if coordination advantages of vertical integration exist in the electricity sector, they should be present in the R&D activities of the utilities (Jamash and Pollitt 2008). (Ownership) unbundling would reduce or destroy this coordination advantages, which would also have consequences for the research projects. Moreover, unbundling can change the type of R&D projects. Integrated firms are not solely but also interested in research projects that concern the interrelation between the different stages of the industry, as they can benefit on every single stage, in contrast to a single generation or grid company.

On the other hand, utilities that have been forced to (ownership) unbundle the grid stage could now totally concentrate on the generation business or on the grid activities respectively, not anymore distracted by other tasks. In order to maintain or even extend their profits from generation, they could invest more in R&D. Furthermore, effective forms of unbundling could reduce discrimination potentials against non-incumbent firms, thereby stimulating competition.

*Bringing together all the arguments mentioned afore, we cannot draw a clear hypothesis on how (ownership) unbundling affects the amount of electrical firms' R&D expenditures, as possible negative short-run effects of unbundling such as reduced firms size, free riding and the loss of coordination advantages could be at least partly compensated through mergers*

*from a long-run perspective. Furthermore, specialization advantages could increase R&D efforts.*

### **c) Incentive regulation vs. cost-based regulation of the power lines**

During the past 15 years almost all countries of the EU have switched from cost-based forms of network regulation to incentive-based forms of regulation, such as price-caps, revenue-caps or yardstick competition. The main reason for this change has been that under cost-based regulation there were too little incentives for the utilities to operate cost-efficiently and to transfer possible efficiency savings to final consumers via lower prices. Typically, firms could pass on all their costs, once they were approved by the regulator,<sup>10</sup> whereas incentives for a cost-efficient realization of the research projects were rather weak. Under incentive regulation utilities are required to obtain efficiency savings each year, which are passed unto consumers. This mechanism changes the incentives of the firms, as expenditures on risky long-term projects such as R&D could easily be cut in order to increase short-term cost efficiency. This possible decline in R&D spending should be confronted with the firms' incentives to perform the remaining projects more efficiently. However, incentive regulation impedes stranded cost recovery, and furthermore, it raises regulatory and market uncertainty, ultimately delaying and hampering investment (Dobbs 2004, Evans and Guthrie 2005). Finally, it is very likely that incentive regulation changes the structure of R&D projects, as the main focus will lie more on short-term projects than on basic and long-term activities.

The relevant empirical literature is primarily orientated on rate-of-return regulation and the situation in the US. Nelson (1984), looking at US utilities between 1951 and 1978, points out that if policy makers want to accelerate certain generation technologies, thereby increasing specific R&D activities of the firms, they should rather rely on policy instruments that privilege the preferred technologies, than on changes in the allowed rate-of-return. Mayo and Flynn (1988) analyze the effect of rate-or-return regulation on utilities' R&D expenditures in the US for the years 1975 and 1983. Regulation is captured by two variables, namely the allowed rate-of-return and a dummy for R&D investment allowed in the rate base. Their findings show that both variables are important determinants of R&D spending.

*We expect that the introduction of incentive regulation should have a damping effect on R&D investment due to rising regulatory and market uncertainty, due to the impediment of stranded*

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<sup>10</sup> It could be the case that utilities under cost-plus regulation invest too much in R&D ("gold plating" effect). However, for today's situation this argument is not valid, as current challenges for power lines are much bigger than ever before, for example due to smart grids, decentralized generation and reverse power flows.

*cost recovery and due to the incentives of the utilities to perform research projects more cost-efficiently, thereby cutting risky long-term R&D. However, possible effects could be rather weak as incentive regulation regimes in the real world typically include cost-based components (as for instance full or partial cost pass-through for certain R&D expenditures). In addition, utilities' R&D investment in power lines is still relatively small in comparison to their investment in generation, so that changes in power lines investment could be interfered by changes in generation investment.*

### **3.3.2 Private vs. public ownership**

Public ownership enables governments to influence the behavior of utilities directly, which also has implications on firm decisions concerning innovation and R&D. In many European countries the degree of public ownership in the electricity sector has decreased continuously over the last two decades, although speed and degree of privatization varied and still vary widely across countries.<sup>11</sup> Some researchers, as e.g. Sterlacchini (2010), state there is a causal relation between this drop in public ownership and the decline in R&D investment of utilities,<sup>12</sup> and indeed, a number of economic arguments point in this direction.

Privatization is not just a process which affects firms as any other process; it changes objective functions, incentives and the behavior of a firm from scratch (Munari 2003). In contrast to private firms, which are assumed to maximize profits, public firms follow a different objective function, as they try to maximize social welfare. However, according to the public choice theory, politicians and managers of state-owned enterprises can rather behave opportunistically or pursue their own personal interests when deciding on behalf of public enterprises, which sometimes is not welfare optimal and can cause incentive problems (Vickers and Yarrow 1997, Niskanen 1971). As a consequence, efficiency under public ownership may be lower than under private ownership, which is also supported by the property rights theory. Here, it is argued that private firms better mitigate agency problems between managers and owners of a firm due to internal control factors such as a more efficient firm structure, corporate governance and better monitoring opportunities, but also because of external control factors such as greater discipline that arises from the presence of capital markets and the threat of going bankrupt (Vickers and Yarrow 1997). Empirical research confirms the higher efficiency of private firms, see Megginson (2001) for a survey.

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<sup>11</sup> There are some exceptions from this trend as e.g. the German utility ENBW.

<sup>12</sup> One could argue that previous R&D spending was too high from a social welfare economic perspective. But certainly, today's requirements for technological progress in the electricity sector – and therefore also for R&D efforts and R&D spending of the utilities – are expected to be higher than 20 years ago. In addition, Helm and Thompson (1991) claim that underinvestment causes higher social costs than overinvestment.

The different incentives and objective functions of state-owned enterprises lead to the situation that R&D activities of public firms differ from private firms' activities. Research projects of public firms are typically more long-term orientated with a stronger focus on broader national goals in order to generate public goods (Sanyal and Cohen 2009, Munari 2003). This holds in particular for the electricity sector, where negative externalities like emissions or other forms of pollution have become a big issue. Furthermore, state controlled companies perform more basic research that is much riskier and they also have a greater willingness to share the results of their R&D process within the national system.<sup>13</sup> This is not true for private firms, where property rights and patents play a much bigger role, see Munari (2003). Privatized firms concentrate more on their core businesses, reduce risky long-term projects and focus more on applied research, which can be commercialized easier and in a shorter time period (Munari and Sobrero 2003, Munari et al. 2002).

To sum up, due to its objective function as welfare maximizers, public utilities have greater incentives to invest in costly basic and long-term research, which is strongly connected to overall welfare (in particular if concerning public goods or the avoidance of negative externalities). In contrast, the underlying market pressure and control mechanisms of private utilities could lead to a too strong focus on short-term goals, thereby not correctly accounting for long-term decisions of the firms such as basic R&D. More efficient private firms are also more likely to reduce overheads and unproductive slack resources within the R&D department. *Ultimately, we anticipate that a higher share in public ownership leads to a higher level of R&D investment by the utilities.*<sup>14</sup>

A confirmation of this hypothesis would be in line with most of the empirical evidence available for other industries. Munari et al. (2002) consider three European and one Japanese former monopolists that have been privatized, including the partial privatization of the Italian utility ENEL. For the European firms, the authors find a reduction in R&D expenditures, a decrease in the number of R&D personnel, a shift towards applied and commercial projects, and a higher patent activity per researcher. In a recent paper, Munari et al. (2010) perform a multi-industry analysis of 1000 publicly-traded European companies from various industries

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<sup>13</sup> It is not very likely that electrical equipment manufacturers will perform more costly basic research with public goods characteristics, thereby replacing privatized utilities research investments, as the profit expectations from this kind of research are rather low (Sanyal and Cohen 2009).

<sup>14</sup> The effects mentioned so far also hold for partially privatized firms, but on a proportional basis depending on the degree of privatization, see Munari (2003). The higher the private share in a firm the stronger the discontinuity with previous practices and the greater the effect on innovative activities of the underlying firm.



for the year 1996. They do not find a positive impact of state-ownership on R&D intensity. However, cross-sectional data may not be appropriate for analyzing this causal relation, as longitudinal effects are important in this matter.

#### **4. Data and descriptive statistics**

The main data sources are Platts PowerVision, Datastream, OECD, Eurostat, EU documents and annual reports of the underlying firms. Our data set is an unbalanced panel including 20 European electricity utilities over a period from 1985 until 2010. The utilities are located in eight European countries, which are Austria (EVN, Verbund), Czech Republic (CEZ), Finland (Fortum), France (EDF, GDF Suez), Germany (E.ON, ENBW, MVV, RWE, Vattenfall Europe), Italy (Enel, Terna), Spain (Endesa, Iberdrola, Red Electrica), and the UK (National Grid, Powergen, Scottish and Southern Energy, Scottish Power). R&D data of European utilities is difficult to obtain, in contrast to the US. In order to get our dependent variable, R&D expenditures of the utilities, *RD*, we started with a list of the 200 biggest generators in Europe, obtained from Platts. After dropping the utilities that are not available in Datastream as they are not listed on a stock exchange, after excluding the generators that are auto-producers, banks and whose main focus is not on electricity (according to the top two 4-digit SIC codes), and after omitting firms for which R&D data was only available for a maximum of five years, we derived at a sample size of 20 electrical firms. Although this number seems small, our sample is largely representative for the European electricity sector and for the electricity sector in each country respectively (similar to Cambini and Rondi 2010). At the EU level these firms generate more than 50% of total generation, at the country level our sample includes the most important utilities, except Spain (where Gas Natural is absent due to missing R&D data) and the UK (where we can only include Powergen, Scottish and Southern Energy, and Scottish Power). Our sample is not only restricted to generators, as we included the TSOs of Italy (Terna), Spain (Red Electrica) and the UK (National Grid). In Austria and France the TSOs APG and RTE are only legally unbundled (according to the ITO model), and therefore still owned by their parent companies Verbund and EDF, which belong to our sample. The same is true for the German utilities ENBW and RWE, with their corresponding transmission grid area. The remaining transmission grid area in Germany is now operated by two ownership unbundled TSOs (Tennet and Elia), as E.ON and Vattenfall Europe sold them in 2009 and 2010. As our sample period ends in 2010 all big four German utilities can be considered as legally unbundled.

The variables of main interest are the public ownership and regulatory variables. For public ownership we constructed a self created dummy variable, *PO50*, which takes on a value of 1 if the public share in a firm is above 50 percent, 0 otherwise. For a few years it is rather difficult to clearly identify the exact share of public ownership, for instance because of cross-ownership patterns among utilities, or because of mergers or ownership restructurings taking place in the middle of a year. Therefore, we decided to use an additional indicator, *PO*, that measures the general level of public ownership of electricity companies in a particular country for robustness reasons. *PO* takes on the value 4 if utilities are public, 3 if they are mostly public, 2 if they are mixed, 1 if they are mostly private, and 0 if they are private.

Our six regulatory variables are: the starting point of the regulatory reform process, *REG*, ownership unbundling, *OU*, overall degree of vertical separation, *OVS*, incentive regulation, *IR*, liberalized wholesale market, *LWM*, and third party access to the transmission grid, *TPA*. The regulatory variables are coded in a way that larger values indicate more stringent regulation. Thus, *REG* takes on the value 1 once the European regulatory reform process has started in the year 1997 according to the first internal electricity market directive 96/92/EC. For the years prior to this event the dummy variable is equal to 0. In a few countries as for instance in the UK the reform process has even started prior to this directive. The self constructed variable *OU* is coded as 1 if there is ownership unbundling of the transmission grid, and 0 if there is no *OU*.<sup>15</sup> In order to additionally capture the country specific degree of unbundling on the distribution lines we use *OVS*, which is equal to 2 if the overall degree of vertical separation is unbundled, 1 if it is mixed and 0 if it is integrated. *IR* is a self created dummy variable that is equal to 1 in case incentive regulation of the distribution lines has been introduced, 0 otherwise. The existence or non-existence of a liberalized wholesale market for electricity is coded as 1 = *LWM*, and 0 = no *LWM*. *TPA* is 2 if there is regulated third party access, 1 if third party access is negotiated, and 0 if there is no third party access. We also use a modified version of *TPA* (*TPA\_mod*) for a robustness check, which counts the years until negotiated or regulated *TPA* starts. This variable is restricted to integer values between 0 and 5, implying that once *TPA* has been introduced, *TPA\_mod* is set to 0. If the introduction of *TPA* will be in more than 5 years, *TPA\_mod* is still set to the maximum value of 5. All sources and variable definitions are listed in Table 1, descriptive statistics are provided in Table 2.

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<sup>15</sup> An unbundling variable of the transmission grid is also available from OECD Regulation Database, but this variable does not account for the important distinction between legal and ownership unbundling.

## 5. Empirical specification and results

### 5.1 Econometric modeling

For the selection of our estimation techniques we had to consider two points that concern our dataset and, which in addition, concern the nature of firm R&D spending. The first point deals with the observation that in reality all firms undertake capital investment, but not all firms perform R&D investment. R&D decisions of firms can be described as a two-step process. First of all, the firm has to decide whether to conduct R&D or not. In case the answer is no, there is no second step; in case the answer is yes, the question arises how much it wants to invest in R&D. Typically, these kinds of firm decisions are econometrically tackled as a censoring problem implying the application of a tobit model or as a sample-selection problem implying the application of a Heckman-type model (Sanyal and Cohen 2009, Cohen and Sanyal 2004). However, those two models do not apply to our data set, as we only consider utilities that performed R&D in the past.<sup>16</sup> The second point reflects the situation that firms usually choose a rather stable level of R&D spending or of R&D intensity (R&D spending divided by sales), as “[t]he national wherewithal to carry out energy R&D cannot be turned on and off like a light switch when needed” (Dooley 1998, p. 554). One main reason for this is the fact that labor costs of the R&D department are relatively high and constant, as researchers are highly educated, difficult to find and also need some time to derive at utilizable results. For this reason the usage of a static model specification seems to be superior to a dynamic one, as the lagged dependent variable would explain by far most of the current level of R&D spending, thereby upstaging the causal relations of the other variables. Finally, we employ a fixed-effects estimator for our panel data analysis, controlling for firm and time-fixed effects.

We use the following model specification, in order to analyze the impact of public ownership and regulation on R&D spending of the utilities:

$$\ln RD_{it} = \alpha + \beta (\mathbf{firm\ factors})_{it} + \gamma (\mathbf{market\ factors})_{it} + \delta (\mathbf{public\ ownership})_{it-1} + \phi \mathbf{regulation}_{it-1} + \varphi_i + \eta_t + \psi_{it}, \quad (1)$$

where  $\ln RD_{it}$  is the log of firms' R&D expenditures, the subscript  $i$  denotes the firm and  $t$  stands for the year. Firm-fixed effects and year-specific effects are captured by  $\varphi_i$  and  $\eta_t$ , and

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<sup>16</sup> For many smaller electrical companies, which are not included in our sample, Datastream does only provide missing values for firms' R&D expenditures. We do not know whether a missing value indicates that a firm does not conduct any research or whether there is no data available.

$\Psi_{it}$  is the error term assumed to be i.i.d. Firm factors, market factors, public ownership and regulation are vectors that consist of the variables described before. Time lags of regulation and public ownership are used to mitigate endogeneity problems. In addition, we assume that changes in these variables need time to be reflected in the level of R&D investment.

In order to deal with the research question raised in the introduction we make use of different variables and strategies. First, we want to assess the overall impact of privatization and the regulatory reform process on R&D expenditures. Thus, *PO50* and *REG* are the only privatization and regulatory variables included in our first step analysis. However, regulation is a dynamic process that consists of many different measures, which can be modified independently of each other and, which therefore, should be considered independently of each other. In a second step, we make use of all regulatory variables described before, in order to depict the whole regulatory process as comprehensively as possible. The main reason for the whole regulatory reform process has been the creation and establishment of effective competition on the electricity market. In an extension to the second step, we therefore incorporate a measure of market concentration (including squared terms) in our analysis, in order to assess the type of relation between competition and innovative investment.

Finally, it can get quite difficult to separate the different effects of privatization, regulation and (nearing) competition on R&D investment and the whole innovative process, see Jamasb and Pollitt (2008). However, we try to disentangle these potentially coincident relations by the use of a long time horizon and by the application of different model specifications, where we can further lag our main regulation and ownership variables.

## 5.2 Results

Table 3 presents our findings for the first step analysis. Due to the unbalanced nature of our data set and due to the fact that some variables are not available across the whole sample, we report the results for various model specifications, which differ according to the variables included. The main results here are in line with our expectations, namely that public ownership has a positive and highly significant influence on R&D spending of European utilities, while the overall impact of regulation (according to the start of the European regulatory reform process in the year 1997) is negative, although only significant at the 10% level. Thus, the general pressure of cost reductions, rising uncertainty and competitive pressure, caused by the liberalization process, seem to have a damping overall effect on R&D, and firms invest less than prior to the regulatory reform process. Simultaneously, privatization is bad for R&D investment of the utilities, in accordance to Sterlacchini (2010). This applies for both specifi-

cations shown in Table 3, which only differ with regards to the included cash flow in specification (2), which reduces the number of observations to 113, thereby widening the significance intervals such that some of the control variables lose significance. However, firm size (log sales) has a positive effect on R&D expenditures, in contrast to the negative effect of higher leverage and the share in hydro power generation. All other variables remain insignificant.

The weakly significant negative impact of overall regulation is a first indication that different regulatory measures could affect R&D investment of utilities differently, which is confirmed by our results of the second step analysis (see Tables 4a+b), where we can have a deeper and more comprehensive look into the subject. Again, different specifications are presented, which always include the ownership and regulatory variables, but differ by the included control variables. In the first specification we only include company size as a control, in the second specification we further account for demand shocks and the leverage ratio,<sup>17</sup> in the third and fourth specifications we additionally control for the shares in hydro and nuclear generation. Finally, specifications (5), (6a) and (7a) only differ to the first three specifications due to the fact that they include the C1 market concentration index, while (6b) and (7b) additionally incorporate squared terms of C1. In all regressions we employ the fixed-effects estimator, with the exception of specification four, where we make use of the pooled OLS technique for robustness reasons. Our main results are the following:

First, a higher level of public ownership has a significant positive influence on R&D spending, which is true for all six specifications. This confirms our first step analysis and is also in line with most of the empirical evidence available for other industries, see for instance Munari et al. (2002). There exist at least two explanations for that. First, privatization is assumed to increase efficiency of firms, which clearly also applies for the carrying out of R&D projects, due to less overheads and slack resources in the R&D department. Second and potentially more important, private firms have much weaker incentives to perform particularly costly basic and long-term research (often with public good characteristics) than public firms.<sup>18</sup> The reasons are different objective functions, as privatized firms are not any more welfare maximizers but profit maximizers.

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<sup>17</sup> We have not included the log of free cash flow here, as we would lose many observations due to missing values. However, specifications two till six were also carried out with the log of free cash flow and all results hold up.

<sup>18</sup> Unfortunately, we only have data on the total amount of R&D investment of a utility and not separately for basic and applied research. Therefore, we can only formulate this last point as a strong presumption.

Second, we cannot provide a clear answer to the question how unbundling and ownership unbundling in particular influence R&D expenditures. While OU of the transmission grid has mostly an insignificant and positive sign in the different specifications, in one specification it is significant and negative; OVS, as a measure of the overall degree of unbundling (including both transmission grid and distribution lines), also takes on varying signs, but again only once significant. Thus, possible negative effects of unbundling such as reduced firms size, free riding or the loss of coordination advantages are counteracted by specialization advantages or mergers from a more long-term perspective. In contrast to Gugler et al. (2011), who find that ownership unbundling has a significantly negative impact on capital investment spending in the electricity sector, we cannot detect a clear impact on R&D spending.

Third, we are not able to find a negative impact of incentive regulation on R&D investment, as IR is insignificant in all specifications. The possible delaying and dampening effect of incentive regulation on R&D expenditures, caused by higher levels of uncertainty, cannot be confirmed by empirical evidence. However, real world incentive regulation regimes typically include cost pass-through components (in particular for certain R&D expenditures), which could neutralize the effects of incentive regulation on R&D investment and which can explain our result here.

Fourth, market entry regulation is an important determinant of R&D spending. However, different components of entry regulation do not all affect R&D in the same way. In line with our expectations, we find that the existence of a liberalized wholesale market attracts new investment in R&D, as LWM has a strong positive and highly significant sign in all specifications. The introduction of a free wholesale market facilitates the creation of a more competitive electricity sector. Due to the nature of our dataset, we primarily look at former incumbent utilities, and can further conclude that incumbents invest more in R&D in order to “escape” competition. In contrast, third party access to the transmission grid has a negative and highly significant impact on R&D spending of the utilities in all specifications. Anticipating liberalization former incumbents seem to fear drastically changed market and regulatory framework conditions, initiated through stepwise simplification of TPA, and therefore nearing competition (which is further confirmed by a robustness check shown below). This is associated with the pressure of cost-cutting, higher uncertainty and additional risks, such that utilities are forced to reduce their R&D activities. The fact that third party access to the grid has been simplified in a country, before a wholesale market has been introduced leads to the situation

that the effect of nearing competition on utilities R&D investment has already been absorbed by TPA and is therefore not any more influenced by the introduction of a LWM.

Fifth, the degree of market concentration (C1) has a negative and significant sign in specifications (5), (6) and (7). This implies that a higher level of competition, which is equivalent to a lower degree of market concentration, has a positive impact on R&D expenditures of European utilities. Since we primarily consider former incumbents, it can be assumed that more competitive pressure leads to the situation that the incumbent invests more in order to “escape” competition, which is in line with our results for the existence of a liberalized wholesale market. One should have in mind that the present level of competition in the electricity sector is rather low in comparison to other sectors. As shown in specifications (5b, not reported here) (6b) and (7b) rather high levels of competition could work in the opposite direction, since squared terms of C1 have a positive although only slightly significant sign. This finding indicates that the relationship between competition and R&D investment seems to be non-linear and that it can be described as inverted U-shaped according to Aghion et al. (2005).

Out of the firm-specific control variables firm size has the expected highly significant positive sign in all specifications, implying that bigger firms spend more on R&D than smaller ones. Furthermore, the leverage ratio has a negative effect on R&D expenditures, even though only twice significant. Higher leverage seems to prevent utilities from investing more in R&D due to more constrained financial resources. In contrast, free cash flow is not an important determinant for utilities’ R&D spending, as it is always insignificant. Since it consists of many missing values leaving other results unchanged, it is eliminated from our analysis. Firm-specific shares in generation technologies such as in hydro or nuclear power generation influence R&D spending. While a higher share in hydro generation has a significant negative effect on research investment as this technology is relatively stable with regard to new innovations, a higher share in nuclear generation has an increasing influence on investment; however, significance is not given in all specifications. Finally, electricity demand growth does not confirm the demand-pull hypothesis, after which market demand would be the main force of R&D investment.

### **5.3 Robustness**

In order to check the robustness of our results, we make use of further model specifications that are presented in Table 5. First, to control for additional firm size effects, we replace our dependent variable by R&D intensity all else equal. All main results hold up and log sales is not any more significant as expected. Second, due to the concerns raised in section 4, we re-

place the firm specific public ownership variable by a variable measuring the general level of public ownership in a country (PO). Again, we get the same results, only C1 loses significance. Third, we use TPA\_mod instead of TPA to have a more precise measure for nearing competition, which counts the years until TPA starts. This new measure for nearing competition is positive and highly significant, implying that the less years it takes until TPA starts the less utilities invest in R&D. Other results even increase in significance. Furthermore, we include a further lag of the public ownership and regulatory variables in our regressions to control for additional long-term effects and again our main findings do not change. Finally, we incorporate our unbundling, respectively market entry variables separately of each other in our regressions to account for possible multicollinearity,<sup>19</sup> but results remain robust. The underlying tables are available upon request.

The problem of endogeneity or reverse causality is always a serious concern in this kind of analysis, although it seems of minor importance in our case. Regulatory reforms were not primarily focused on the R&D activities of the utilities if at all, rather prices and later on capital investment have been on the agenda of regulators and policymakers. However, we tried to account for that by using lagged regulatory reform variables, and in addition, we applied standard Granger causality tests in order to test for causality. Ultimately, we could not find evidence of bidirectional causality in our model specifications.

## **6. Concluding remarks and policy implications**

R&D investment of major European utilities dropped remarkably during the last two decades, even though one can observe a slight increase from 2007 onwards (Burger and Weinmann 2012). At the same time the need for new innovations in the energy and electricity sector is continuously high. For instance, the whole electricity industry is still responsible for approximately one quarter of global greenhouse gas emissions (Stern 2008). In addition, a report of the Advisory Group on Energy (2005) for the European Commission states that investment in energy R&D should be four times as high as it is right now. The aim of this paper is to shed light on possible reasons for this drop in utilities' R&D spending. In particular, we want to analyze if different measures of the regulatory reform process, the anticipation of liberalization, increased levels of competition or the privatization process contributed to this steep decline.

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<sup>19</sup> The correlation between LWM and TPA is 0.68 and between OU and OVS it is 0.64.



We find that the overall influence of regulation on R&D investment is negative, and weakly significant, while privatization of utilities has a strong negative impact, pointing to a possible market failure in costly basic research with public goods characteristics. Furthermore, empirical evidence shows that nearing competition has a dampening effect on R&D spending, but once the market and regulatory framework conditions have been established, higher levels of competition positively influence R&D and former incumbents invest more in order to “escape” competition. However, the recent level of competition in the electricity market is rather low in comparison to other industries and “too” high levels of competition may negatively influence R&D spending, as the relation between competition and innovative investment seems to be inverted U-shaped. In contrast, (ownership) unbundling and incentive regulation do not directly affect research expenditures of the utilities.

In order to spur R&D investment of utilities, policymakers and regulators have different possibilities, which may be used as complements. First, the currently low level of competition in the electricity sector should be further increased, for instance through the establishment of pro-competitive framework conditions. Second, the privatization of a utility should be accompanied by clear regulatory guidelines, which ensure that costly and welfare enhancing basic and long-term research (often with public goods characteristics) will not be completely cancelled or replaced by short-term research activities that are easier to commercialize and that deliver more direct profits. Third, as the regulatory reform process changed the character and the lifetime of R&D activities – in the UK for instance, the lifetime of R&D projects dropped from five to seven years to less than three years after the regulatory reforms and is assumed to reach one year after full competition (Dooley 1998) – one could think about incentive programs of the government or other kinds of support schemes. However, according to Jamasb and Pollitt (2008) it is extremely difficult to establish support mechanisms, which deliver the “right” incentives. In any case, more research on the interrelation between regulatory reforms and R&D is urgently needed.

## Literature

Advisory Group on Energy. (2005). Key Tasks for Future European Energy R&D. *Report for the European Commission* .

Aghion, P., Bloom, P. N., Blundell, R., & Griffith, R. (2005). Competition and Innovation: An inverted-U Relationship, *Quarterly Journal of Economics*. 120, pp. 701-728.

Alesina, A., Ardagna, S., Nicoletti, S., & Schiantarelli, F. (2005). Regulation and Investment. *Journal of the European Economic Association* , 3 (4), pp. 791-825.

Arocena, P., Saal, D., & Coelli, T. (2009). Measuring Economies of Horizontal and Vertical Integration in the U.S. Electric Power Industry: How Costly is Unbundling? *Working Paper RP 0917, Aston Business School, UK*.

Arrow, K. J. (1962). Economic Welfare and the Allocation of Resources to Invention. In R. R. Nelson, *The Rate and Direction of Economic Activity*. New York: Princeton University Press.

Balmert, D., & Brunekreeft, G. (2010). Deep-ISOs and Network Investment. *Competition and Regulation in Network Industries* , 11 (1), pp. 27-49.

Blyth, W., Bradley, R., Bunn, D., Clarke, C., Wilson, T., & Yang, M. (2011). Investment Risks Under Uncertain Climate Change Policy. *Energy Policy* , 35, pp. 5766-5773.

Bond, S., & van Reenen, J. V. (2007). Microeconomic Models of Investment and Employment. In J. Heckman, & E. Leamer, *Handbook of Econometrics* (pp. 4417-4498). Elsevier, Edition 1, volume 6, 6a.

Bond, S., Harhoff, D., & van Reenen, J. V. (2005). Investment, R&D and Financial Constraints in Britain and Germany. *Annales d'Économie et de Statistique* , 79/80, pp. 433-460.

Bortolotti, B., Cambini, C., Rondi, L., & Spiegel, Y. (2011). Capital Structure and Regulation: Do Ownership and Regulatory Independence Matter? *Journal of Economics and Management Strategy* , 20 (2), pp. 517-564.

Brunekreeft, G., & Bauknecht, D. (2009). Regulierung und Innovationstätigkeit: Eine Ökonomische Perspektive. In M. Eifert, & W. Hoffmann-Riem, *Innovationsfördernde Regulierung* (pp. 243-256). Berlin: Duncker&Humblot.

Burger, C., & Weinmann, J. (2012). ESMT Innovation Index 2010 - Electricity Supply Industry. *ESMT Business Brief* .

Cambini, C., & Rondi, L. (2010). Incentive Regulation and Investment: Evidence from European Energy Utilities. *Journal of Regulatory Economics* , 38, pp. 1-26.

Cassiman, B., Colombo, M. G., Garrone, P., & Veugelers, R. (2005). The Impact of M&A on the R&D Process: An Empirical Analysis of the Role of Technological- and Market-relatedness. *Research Policy* (34), pp. 195-220.

- Cohen, L. R., & Sanyal, P. (2004). R&D Choice in Restructured Industries: In-house v/s Collaborative Research in the US Electricity Industry. *Working Paper Series, Brandeis University, Waltham* .
- Cumming, D. J., & Macintosh, J. G. (2000). The Determinants of R&D Expenditures: A Study of the Canadian Biotechnology Industry. *Review of Industrial Organization* , 17, pp. 357-370.
- Defeuilley, C., & Furtado, A. (2000). Impacts de l'ouverture a la concurrence sur la R&D dans le secteur electrique. *Annals of Public and Cooperative Economics* , 71 (1), pp. 5-28.
- Delaney, J. B., & Honeycutt, T. C. (1976). Determinants of Research and Development Activity by Electric Utilities: Comment. *Bell Journal of Economics* , 7 (2), pp. 722-725.
- Dobbs, I. M. (2004). Intertemporal Price Cap Regulation under Uncertainty. *Economic Journal* , 114 , pp. 421-440.
- Dooley, J. J. (1998). Unintended Consequences: Energy R&D in a Deregulated Energy Market. *Energy Policy* , 26 (7), pp. 547-555.
- Evans, L. T., & Guthrie, G. A. (2005). Risk, Price Regulation, and Irreversible Investment. *International Journal of Industrial Organization* , 23 (1-2), pp. 109–128.
- Gilbert, R. J., & Newbery, D. M. (1982). Preemptive Patenting and the Persistence of Monopoly. *American Economic Review* , 72 (3), pp. 514-526.
- Gugler, K., Rammerstorfer, M., & Schmitt, S. (2011). The Trade-offs in Electricity Markets - A Cross Country Study. *Working Paper, Research Institute for Regulatory Economics, WU Vienna* .
- Hall, B. H. (1992). Investment and Research and Development at the Firm Level: Does the Source of Financing Matter? *Working Paper no. 92-194, Department of Economics, University of California, Berkeley* .
- Hall, B. H. (1990). The Impact of Corporate Restructuring on Industrial Research and Development. *Brookings Papers on Economic Activity. Microeconomics* , pp. 85-124.
- Hall, B. H., & van Reenen, J. (2000). How Effective are Fiscal Incentives for R&D? A Review of the Evidence. *Research Policy* , 29 (4-5), pp. 449-470.
- Helm, D., & Thompson, D. (1991). Privatized Transport Infrastructure and Incentives to Invest. *Journal of Transport Economics and Policy* , 15, pp. 231-246.
- Holmstrom, B. (1989). Agency Costs and Innovation. *Journal of Economic Behavior and Organization* , 12, pp. 305-327.
- Jaffe, A. B. (1986). Technological Opportunity and Spillovers of R & D: Evidence from Firms' Patents, Profits, and Market Value. *The American Economic Review* , 76 (5), pp. 984-1001.

- Jamasb, T., & Pollitt, M. (2008). Liberalisation and R&D in Network Industries: The Case of the Electricity Industry. *Research Policy* , 37, pp. 995-1008.
- Joskow, P. (2002). Electricity Sector Restructuring and Competition: A Transactions-cost Perspective. In E. Broussau, & J.-M. Glachant, *The Economics of Contracts: Theories and Applications*. Cambridge: Cambridge University Press.
- Kamien, M., & Schwartz, N. (1975). Market Structure and Innovation: A Survey. *Journal of Economic Literature* , 13 (1), pp. 1-37.
- Keller, K., & Wild, J. (2004). Long-term Investment in Electricity: A Trade-off Between Co-ordination and Competition? *Utilities Policy* , 12, pp. 243–251.
- Kim, J., Kim, Y., & Flacher, D. (2012). R&D Investment of Electricity-generating Firms Following Industry Restructuring. *Energy Policy (forthcoming)* .
- Kucsera, D., & Schmitt, S. (2012). Monopoly Rights in an Ex-monopoly Industry: The Impact of the European Electricity Reforms on Electricity-related Patent Activities. *Working Paper, Research Institute for Regulatory Economics, WU Vienna* .
- Kwoka, J. (2002). Vertical Economies in Electric Power: Evidence on Integration and its Alternatives. *International Journal of Industrial Organization* , 20 (5), pp. 653–671.
- Laffont, J., & Tirole, J. (1993). Privatization and Incentives. In J. Laffont, & J. Tirole, *The Theory of Incentives in Procurement and Regulation*. Cambridge, USA: MIT Press.
- Mayo, J. W., & Flynn, J. E. (1988). The Effects of Regulation on Research and Development: Theory and Evidence. *Journal of Business* , 61 (3), pp. 321-326.
- Meggison, W., & M., N. J. (2001). From State to Market: A Survey of Empirical Studies on Privatization. *Journal of Economic Literature* , 39 (2), pp. 321-389.
- Motta, M. (2004). *Competition Policy*. New York: Cambridge University Press.
- Munari, F. (2003). Does Ownership Affect Innovation? Assessing the Impact of Privatisation Processes on Innovation Activities. *European Business Organization Law Review* , 4, pp. 553-571.
- Munari, F., & Sobrero, M. (2003). Privatization's Effects on R&D Investments. In M. Calderini, P. Garrone, & M. Sobrero, *Corporate Governance, Market Structure and Innovation*. London.: Edward Elgar.
- Munari, F., Oriani, R., & Sobrero, M. (2010). The Effects of Owner Identity and External Governance Systems on R&D Investments: A Study of Western European Firms. *Research Policy* , 39, pp. 1093-1104.
- Munari, F., Roberts, E., & Sobrero, M. (2002). Privatization Processes and the Redefinition of Corporate R&D Boundaries'. *Research Policy* , 31 (1), pp. 33-55.

- Nelson, R. A. (1984). Regulation, Capital Vintage, and Technical Change in the Electric Utility Industry. *Review of Economics and Statistics* , 66 (1), pp. 59-69.
- Newbery, D. (2005). Introduction. *Energy Journal, A Special Issue on European Electricity Liberalization* , pp. 1-10.
- Niskanen, W. A. (1971). *Bureaucracy and Representative Government*. Chicago: Aldine-Atherton.
- Pollitt, M. (2008). The Arguments for and against Ownership Unbundling of Energy Transmission Networks. *Energy Policy* , 36 (2), pp. 704–713.
- Sanyal, P. (2007). The Effect of Deregulation on Environmental Research by Electric Utilities. *Journal of Regulatory Economics* , 31, pp. 335-353.
- Sanyal, P., & Cohen, L. R. (2009). Powering Progress: Restructuring, Competition and R&D in the U.S. Electric Utility Industry. *The Energy Journal* , 30 (2), pp. 41-80.
- Sanyal, P., & Ghosh, S. (2010). Product Market Competition and Upstream Innovation: Evidence from the US Electricity Market Deregulation. *Working paper, Brandeis University* .
- Scherer, F. M. (1982). Demand-Pull and Technological Invention: Schmoockler Revisited. *The Journal of Industrial Economics* , 30 (3), pp. 225-237.
- Scherer, F. M. (1965). Firm Size, Market Structure, Opportunity, and the Output of Patented Inventions. *The American Economic Review* , 5 (1), pp. 1097-1125.
- Schmoockler, J. (1966). *Invention and Economic Growth*. Cambridge: Harvard University Press.
- Sterlacchini, A. (2010). Energy R&D in Private and State-owned Utilities: An Analysis of the Major World Electric Companies. *Working Paper, Università Politecnica delle Marche, Ancona (Italy)* .
- Stern, N. (2008). The Economics of Climate Change. *The American Economic Review, Papers and Proceedings of the One Hundred Twentieth Annual Meeting of the American Economic Association* , 98 (2), pp. 1-37.
- Vickers, J., & Yarrow, G. (1997). *Privatization: An Economic Analysis*. Cambridge, Massachusetts: MIT Press.
- von Hirschhausen, C., Beckers, T., & Brenck, A. (2004). Infrastructure Regulation and Investment for the Long-term - An Introduction. *Utilities Policy* , 12, pp. 203-210.
- Wilder, R. P., & Stansell, S. R. (1974). Determinants of Research and Development Activity by Electric Utilities. *Bell Journal of Economics and Management Science* , 5 (2), pp. 646-650.

**Figure 1: R&D spending of electrical utilities between 1985 and 2010**

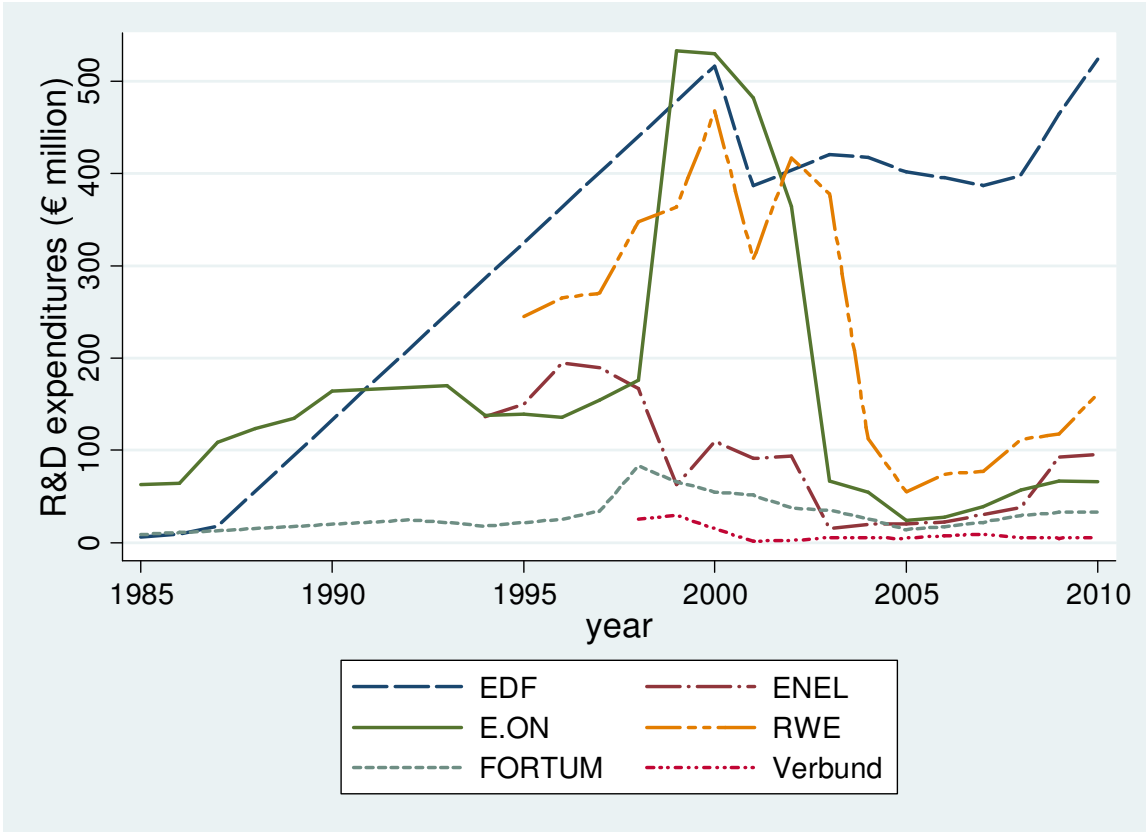


Figure 1 illustrates R&D expenditures (deflated at 2005 constant prices) for a subsample of six utilities. R&D spending of the other 14 utilities analyzed follows a similar trend and is not presented here for reasons of clarity.

**Table 1: Variable Definitions**

<b>Variable</b>	<b>Variable description</b>	<b>Source</b>
<b>R&amp;D investment, RD</b>	R&D investment of a firm (in thousand Euros)	Datastream + annual reports
<b>Sales, sales</b>	Sales of a firm (in thousand Euros)	Datastream
<b>Free cash flow, cash flow</b>	Free cash flow = EBIT * (1-tax rate) + depreciation - change in working capital – CAPEX (in thousand Euros)	Datastream
<b>Leverage, leverage</b>	Leverage = long-term debt / total assets	Datastream
<b>Share in hydro power generation, share in hydro</b>	Share in hydro power generation = hydro power capacity / total generation capacity	Platts
<b>Share in nuclear power generation, share in nuclear</b>	Share in nuclear power generation = nuclear power capacity / total generation capacity	Platts
<b>C1 market concentration index, C1</b>	Market share of the biggest generator in a country measured in generation capacity	Platts
<b>Electricity consumption, demand</b>	Country-specific electricity consumption (in GWh)	OECD
<b>Starting point of the regulatory reform process, REG</b>	As unique European starting point of the regulatory reform process we choose the first internal energy market directive 96/92/EC of the European Commission, in force since 1997	EU
<b>Firm specific degree of public ownership, PO50</b>	Firm specific degree of public ownership (0 = public ownership below 50 percent, 1 = public ownership above 50 percent)	Annual reports + internet search
<b>Public ownership, PO</b>	Ownership of the largest companies in the generation, transmission, distribution and supply segments of the electricity industry in a country ( 0 = private, 1 = mostly private, 2 = mixed, 3 = mostly public, 4 = public)	OECD International Regulation Database
<b>Ownership unbundling, OU</b>	Ownership unbundling of the transmission grid in a country (0 = no OU, 1 = OU)	Publications of the EU Commission + contact with national regulatory authorities
<b>Overall degree of vertical separation, OVS</b>	Overall degree of vertical separation in a country including transmission and distribution lines (0 = OVS is integrated, 1 = OVS is mixed, 2 = OVS is unbundled)	OECD International Regulation Database
<b>Incentive regulation, IR</b>	Introduction of incentive regulation in a country (0 = no incentive regulation, 1 = incentive regulation)	Contact with national regulatory authorities + other papers
<b>Liberalized wholesale market, LWM</b>	Existence of a liberalized wholesale market for electricity in a country (0 = no LWM , 1 = LWM)	OECD International Regulation Database
<b>Third party access, TPA</b>	Third party access to the electricity transmission grid in a country (0 = no TPA, 1 = negotiated TPA, 2 = regulated TPA)	OECD International Regulation Database
<b>Third party access modified, TPA_mod</b>	Years until TPA starts (0 if neg. or reg. TPA already introduced, 1 if neg. or reg. TPA is introduced in the following year, the same for 2, 3, 4, 5 years, if introduction of neg. or reg. TPA in more than 5 years = 5)	Self constructed

**Table 2: Descriptive statistics**

<b>Variable</b>	<b>Number of observations</b>	<b>Mean</b>	<b>Standard Deviation</b>	<b>Min</b>	<b>Max</b>
<b>RD</b>	256	69270.17	123091	292.526	583000
<b>Sales</b>	407	13700000	17600000	379281	92900000
<b>RD/Sales</b>	256	0.0040	0.0049	0.0001	0.0300
<b>Cash flow</b>	391	702711	2269110	-14900000	12400000
<b>Leverage</b>	408	0.2299	0.1496	0	0.6050
<b>Share in hydro</b>	338	0.2385	0.1928	0	0.8019
<b>Share in nuclear</b>	338	0.1683	0.1639	0	0.6022
<b>C1</b>	420	0.3594	0.2315	0.1589	0.9332
<b>Demand</b>	500	289010	161838	37771	543248
<b>PO50</b>	431	0.4802	0.5001	0	1
<b>PO</b>	520	2.0865	1.4632	0	4
<b>OU</b>	520	0.2519	0.4278	0	1
<b>OVS</b>	520	1.025	0.7509	0	2
<b>IR</b>	520	0.3461	0.4762	0	1
<b>TPA</b>	520	1.1134	0.8977	0	2
<b>TPA_mod</b>	520	1.3750	2.0550	0	5
<b>LWM</b>	520	0.4826	0.5001	0	1

The units of the variables correspond to the definitions in Table 1.



**Table 3: The overall impact of privatization and regulatory reforms on R&D investment**

Dependent variable: <b>log RD</b>	(1)	(2)
<b>PO50</b>	1.6459*** (0.1063)	1.2017*** (0.1444)
<b>REG</b>	-0.3754* (0.2165)	-0.5842* (0.3139)
<b>Log sales</b>	0.3659** (0.1546)	0.3097 (0.2077)
<b>Demand growth</b>	-1.5313 (2.8887)	0.0584 (3.3509)
<b>Share in hydro</b>	-13.5670* (6.4723)	-11.8913 (7.6347)
<b>Share in nuclear</b>	16.0318 (9.9729)	-6.4768 (11.3271)
<b>Log leverage</b>	-0.2481** (0.0959)	-0.2147 (0.1243)
<b>Log cash flow</b>		-0.0542 (0.0394)
Time dummies	no	no
R-squared within	0.3304	0.2472
F-test	10.15 (0.00)	3.78 (0.00)
Observations	164	113

Clustered and robust standard errors in parentheses; \*  $p < 0.10$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ ; specifications (1), (2) and (3) employ the two-way fixed effects model

**Table 4a: Regulatory determinants of R&D investment**

Dependent variable: <b>log RD</b>	(1)	(2)	(3)	(4)
<b>PO50 (t-1)</b>	0.8291* (0.4777)	0.8877* (0.4842)	0.9676*** (0.2954)	0.6439*** (0.2125)
<b>OU (t-1)</b>	0.3664 (0.3342)	0.4701 (0.4062)	-0.5633* (0.2877)	0.0977 (0.2315)
<b>OVS (t-1)</b>	0.1548 (0.3587)	0.0407 (0.3736)	-0.2592 (0.2450)	-0.4851** (0.2076)
<b>IR (t-1)</b>	-0.0955 (0.2485)	-0.1072 (0.3200)	0.2122 (0.2167)	-0.0748 (0.2161)
<b>LWM (t-1)</b>	0.7144** (0.3089)	0.8695** (0.3181)	1.4642*** (0.2288)	0.6212** (0.2694)
<b>TPA (t-1)</b>	-0.2238* (0.1270)	-0.3306*** (0.0982)	-0.2495** (0.0886)	-0.5473*** (0.1503)
<b>Log sales</b>	0.6399** (0.2394)	0.6087** (0.2332)	0.6546*** (0.1756)	1.0739*** (0.0781)
<b>Demand growth</b>		-4.5416* (2.5752)	-4.4717 (2.8224)	0.0999 (6.5072)
<b>Log leverage</b>		-0.2722 (0.1629)	-0.3495* (0.1878)	-0.5737*** (0.1521)
<b>Share in hydro</b>			-25.2545*** (4.4226)	2.0379*** (0.4203)
<b>Share in nuclear</b>			16.4326* (7.9081)	2.0310*** (0.5118)
Time dummies	yes	yes	yes	yes
R-squared within	0.3333	0.3626	0.5912	0.8453
F-test	3.18 (0.00)	3.18 (0.00)	4.89 (0.00)	20.42 (0.00)
Observations	248	231	162	162

Clustered and robust standard errors in parentheses; \* p < 0.10, \*\* p < 0.05, \*\*\* p < 0.01; specifications (1), (2) and (3) employ the two-way fixed effects model, (4) uses pooled OLS and for this specification only standard R-squared is reported; the results for all specifications hold up if log cash flow is included, this variable is not reported here as it is always insignificant and as it consists of many missing values, finally reducing the number of observations significantly

**Table 4b: Determinants of R&D investment including C1 market concentration index**

Dependent variable: <b>log RD</b>	(5)	(6a)	(6b)	(7a)	(7b)
<b>PO50 (t-1)</b>	1.1582** (0.4722)	1.1368** (0.4617)	0.8371* (0.4130)	1.2447** (0.4100)	1.1415** (0.4297)
<b>OU(t-1)</b>	0.2788 (0.2598)	0.3117 (0.2618)	0.2084 (0.1904)	-0.3282 (0.2497)	-0.3449 (0.2748)
<b>OVS (t-1)</b>	-0.1819 (0.2958)	-0.1987 (0.3072)	-0.0312 (0.3818)	-0.3050 (0.2478)	-0.2502 (0.2634)
<b>IR (t-1)</b>	0.1652 (0.2080)	0.1655 (0.2746)	0.0916 (0.3012)	0.3627 (0.2277)	0.2993 (0.2500)
<b>LWM (t-1)</b>	0.6161** (0.2662)	0.6758** (0.2777)	0.6041** (0.2719)	1.0684*** (0.1687)	1.0111*** (0.1685)
<b>TPA (t-1)</b>	-0.3362** (0.1390)	-0.3493** (0.1290)	-0.3247** (0.1405)	-0.3231** (0.1253)	-0.3195** (0.1304)
<b>C1</b>	-13.5192** (5.7886)	-12.6646** (5.7901)	-28.643*** (9.0233)	-7.7433 <sup>a</sup> (5.5832)	-15.0764* (8.0021)
<b>C1<sup>2</sup></b>			20.6040* (11.1743)		7.7510 <sup>b</sup> (5.3600)
<b>Log sales</b>	0.8364*** (0.2179)	0.8536*** (0.2253)	0.8938*** (0.2557)	0.7853*** (0.1916)	0.7911*** (0.2087)
<b>Demand growth</b>		-2.8837 (2.3700)	-1.1328 (2.4735)	-4.5702* (2.5260)	-4.0540 (2.6461)
<b>Log leverage</b>		-0.0431 (0.1372)	-0.0368 (0.1326)	-0.1659 (0.2018)	-0.1569 (0.2052)
<b>Share in hydro</b>				-16.2691*** (3.9434)	-16.064*** (3.5771)
<b>Share in nuclear</b>				-2.4400 (12.4371)	-0.7117 (14.1374)
Time dummies	yes	yes	yes	yes	yes
R-squared within	0.4115	0.4162	0.4498	0.5694	0.5741
F-test	4.82 (0.00)	4.30 (0.00)	4.74 (0.00)	4.73 (0.00)	4.63 (0.00)
Observations	241	224	224	155	155

Clustered and robust standard errors in parentheses; \* p < 0.10, \*\* p < 0.05, \*\*\* p < 0.01;

specifications (5), (6) and (7) employ the two-way fixed effects model; the results for all specifications hold up if log cash flow is included, this variable is not reported here as it is always insignificant and as it consists of many missing values, finally reducing the number of observations significantly

a: p-value 0.19; b: p-value 0.15

**Table 5: Robustness checks**

Dependent variable:	(1)	(2)	(3)	(4)	
<b>log RD</b>	Log RD intensity as dep. var.	PO instead of PO50	TPA_mod instead of TPA (t-1)	Lagged reg. var.	Aggregated effects for the years (t-1) and (t-2)
<b>PO50 (t-1)</b>	1.1368** (0.4617)	0.2107* (0.1181)	1.1348*** (0.3604)	1.3238*** (0.4555)	
<b>PO50 (t-2)</b>				0.0804 (0.4292)	<b>PO50: 1.4042**</b>
<b>OU (t-1)</b>	0.3117 (0.2618)	0.2296 (0.2209)	0.2056 (0.2245)	0.3899 (0.2778)	
<b>OU (t-2)</b>				-0.0166 (0.3032)	<b>OU: 0.3733</b>
<b>OVS (t-1)</b>	-0.1987 (0.3072)	-0.2258 (0.2819)	-0.1831 (0.3275)	0.0139 (0.2189)	
<b>OVS (t-2)</b>				-0.4501** (0.1947)	<b>OVS: -0.4361</b>
<b>IR (t-1)</b>	0.1654 (0.2746)	0.1526 (0.2994)	0.2185 (0.2920)	0.1187 (0.3845)	
<b>IR (t-2)</b>				0.3158 (0.4366)	<b>IR: 0.4344</b>
<b>LWM (t-1)</b>	0.6758** (0.2777)	0.5483** (0.2475)	0.5596* (0.2973)	0.8844*** (0.2730)	
<b>LWM (t-2)</b>				-0.1177 (0.2966)	<b>LWM: 0.7667**</b>
<b>TPA (t-1)</b>	-0.3492** (0.1289)	-0.3655** (0.1496)	0.2943*** (0.0794)	-0.2258* (0.1189)	
<b>TPA (t-2)</b>				-0.2394 (0.1697)	<b>TPA: -0.4651***</b>
<b>C1</b>	-12.6646** (5.7901)	-8.5183 (6.8021)	-13.653** (5.7526)	-16.8687*** (4.4633)	
<b>Log sales</b>	-0.1463 (0.2253)	0.8622*** (0.2288)	0.8723*** (0.2512)	0.8971*** (0.2233)	
<b>Demand growth</b>	-2.8836 (2.37)	-1.4234 (2.2799)	-3.3866 (2.2223)	-1.3796 (2.7304)	
<b>Log leverage</b>	-0.0430 (0.1372)	0.0657 (0.1199)	-0.0178 (0.1359)	-0.0867 (0.1466)	
Time dummies	yes	yes	yes	yes	
R-squared within	0.6044	0.3836	0.4211	0.4524	
F-test	8.43 (0.00)	3.86 (0.00)	4.39 (0.00)	3.85 (0.00)	
Observations	224	229	224	218	

Clustered and robust standard errors in parentheses; \* p < 0.10, \*\* p < 0.05, \*\*\* p < 0.01; all specifications employ the two-way fixed effects model; (3)