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Evens SALIES
OFCE

Observatoire Français des Conjonctures Économiques
69, Quai d'Orsay 75340 Paris Cedex 07
Tél : 01 44 18 54 00 Fax : 01 45 56 06 15
E-mail: ofce@ofce.sciences-po.fr Web: http://www.ofce.sciences-po.fr

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INTRODUCTION

Electric utilities are urged to increase both the thermal efficiency of their existing plants, and the substitution of renewable energy resources for fossil fuel in electricity production. In the meantime, they must manage to stabilise future costs by reducing the dependence vis-à-vis oil and gas, the prices of which have shown sharp fluctuations since year 2000. As it is progressively deregulated, the internal energy market is characterised by tremendous institutional changes that have been shaping the industrial structure of the electricity industry. There is now clear evidence that more market forms of mechanisms used between the unbundled system operators, generators and retailers for decision making (governance) have significantly influenced the R&D policy of electric utilities in developed economies. Markard et al. (2004) showed for a sample of several European countries (Germany, Switzerland and the Netherlands) that liberalisation induced changes in the selection of innovations by electric utilities produced by equipment builders and themselves. In addition, increased liberalisation of the European electricity industry has created new opportunities for further internationalisation of already big electric utilities, with the consequence that some electric utilities decided to increase their debts to extend their scope of activities abroad through acquisitions rather than to fund R&D projects. This restructuring gives birth to a more concentrated European oligopoly of electric utilities fringed by smaller entrants, which raises the question whether large firms would have an advantage to achieve the aforementioned objectives.[2] The bottom line is that the EU may not meet its ambitious environmental goal to reduce greenhouse gas emissions by at least 20% by 2020 (Commission of the European Communities, 2007), for it may not have created a sufficiently stable environment that is yet necessary for promoting renewable energy resources.

This cahater studies the determinants of R&D expenditures. To understand the drivers of R&D in the case of the European electricity industry, I follow previous authors and focus on an input albeit imperfect measure of innovation in the electricity industry, namely research and development expenditures (hereafter, R&D). Figure 1 shows the evolution of total R&D expenditures over the period 1980 through to 2007 for a sample of nineteen major European electric utilities.

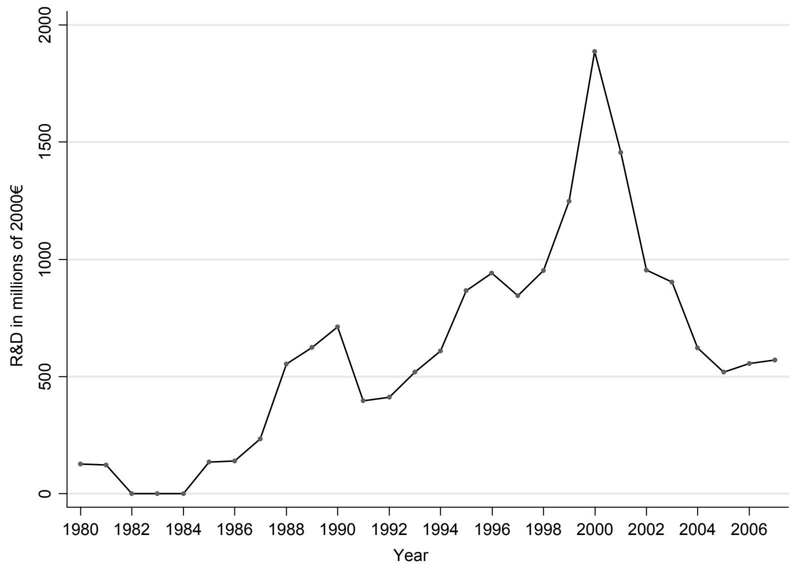

Figure 1 Total R&D expenditures for European electric utilities, 1980–2007

We observe a striking similarity with the trend reversion reported in Sanyal and Cohen (2008) and Sanyal (2007) in the case of U.S. firms, yet the reversion period occurs later for European firms. In the U.S.A., the maximum national value is achieved about 1993, whereas here the peak is in 2000. This dramatic decline was reported for both total R&D (Sanyal and Cohen, 2008) and environmental R&D (Sanyal, 2007) expenses by electric utilities.

Which factors stand behind this decline? The determinants of R&D within the electricity industry in Europe drew the attention of economists following its decline from the early 1980s in the U.S.A. and the U.K. The main reasons advocated by several authors are the higher competition expected from the deregulation of the utilities which increases uncertainty in the value of future revenues (Sanyal and Cohen, 2008; Sanyal, 2007; Margolis and Kammen, 1999). Hence deregulation would act as a disincentive to undertake research activities. A further reason in the U.S.A. was an overall reduction in federal and state funding, more particularly in nuclear, fossiel fuels and biological and environmental R&D (see GAO, 1996, p. 5). Interestingly, this literature suggests it is not deregulation per se that matters but its expected consequences. Sanyal argues that utilities anticipating further deregulation may have cut back on environmental research following the first sign of change. Therefore, actual restructuring, when it happens, would have little impact.[3] More recently, Jamasb and Pollitt (2008) reach the same conclusion on the role of markets liberalisation in explaining the decline in R&D efforts in several European countries. Sanyal (2007, p. 337) suggests that increased competition will lead electric utilities to cut back on R&D, in particular when R&D spending are more directed towards social goals and 'public-interest' (e.g. research on global warming), because such research does not confer short-term cost reduction or efficiency enhancement that would bring private benefits to electric utilities. This negative influence on R&D of expected competitive pressures is reinforced by the public good nature of innovation in electricity due to the negative external effects characterising most environmental problems (Horbach, 2008, p. 165). This tends to limit the scope of private involvement as spillovers reduce the returns from R&D expenditure to private investors (Jamasb and Pollitt, 2008, p. 998).

The purpose of the present article is to provide applied evidence of the combined effect of size and reforms on innovative activity by electric utilities, through a test of the 'Schumpetarian hypothesis', for a sample of twenty European electric utilities with annual observations for the period 1980 to 2007. To our knowledge a pioneer contribution analysing the effect on R&D of size across a panel of electric utilities is the seminal paper of Wilder and Stansell (1974). Their main results, which are stable over the period 1968 through to 1970, are that R&D intensity increases with firm size and that electric utilities perform more R&D associated with electric operations than with other operations. This led them to the conclusion that '…increasing [electric utility] size, either through a merger or internal growth, would have a favourable effect on R&D outlays.' Since the earliest work of Wilder and Stansell (1974), there is a limited number of econometric studies on this general issue as noticed by Jamasb and Pollitt (2008; see also references therein). Sanyal (2007) and Sanyal and Cohen (2008) are the most recently published works on this issue in the case U.S. electric utilities. From their and a couple of previous econometric studie, the elasticity of R&D spending with respect to size lies in the interval 0.84–1.61 with an everage value of 1.24.

These results suggest a positive concentration effect on R&D. Quoting Jamasb and Pollitt (2008, p. 9999), '[s]ince vertical unbundling and horizontal splitting of utilities reduce the size of utilities significantly, these results imply that following restructuring, large reductions in utility R&D spending are possible.'

A statement of the advantage of large firms is given in Cohen and Klepper (1996) and is referred to as 'the R&D cost spreading advantage' (hereafter we shall refer indifferently to their model or to the cost spreading advantage by using the abbreviation 'CSA') thereby the larger the firm then the greater the level of output over which it can apply the fruits and average the costs of its R&D. Apart from Jamasb and Pollitt (2008, p. 999)'s assertion that '[i]t is conceivable that large utilities were better positioned to benefit from the scale factor that new technologies offered', what we know about the relevance of the CSA in the case of European electric utilities is still opened to question.[4]

The main contribution of the present paper is to test a 'weak version' of this hypothesis in the case of European electric utilities. We shall not only analyse the determinants of R&D, with size as the primary variable of interest, but also the effect of factors likely to be responsible for the decrease in aggregated R&D efforts. Next section describes the theoretical framework underlying the CSA hypothesis suggested by Cohen and Klepper, and its relevance for application to electric utilities. We then present the data and the econometric model before estimating the relationship between firm R&D efforts and size conditional on other factors. Several hypotheses are tested in the present paper, of which two are classical in the literature on the economics of innovation. First, the Schumpeterian hypothesis thereby R&D intensity increases with firm size. The second and stronger hypothesis can be termed the 'threshold size hypothesis' (see Symeonidis, 1996; Bound et al., 1984, p. 50). According to this latter hypothesis the amount of R&D expenditures is independent of or declines proportionally with size beyond a certain level of size. This latter test is motivated by the work of Wilder and Stansell (1974) who had not found such threshold size in a panel of more than 200 electric utilities in the late 1960s. These hypotheses can be tested through the theoretical framework of the CSA model applied to electric utilities. We also consider the role of firm's characteristics including financial variables and the differential effects of some characteristics of the country to which they belong. Finally, we summarise the results and provide policy recommendations pertaining to the electricity industry.

THE MODEL

Cohen and Klepper (1996) provided a theoretical and directly estimable model of the close relationship often estimated between firm R&D effort and firm size at the business unit level, that is to say at the level of a firm's activity within a given product market. One consequence of the CSA hypothesis is that R&D efforts should rise proportionally with size at the business unit level. The simple version of the CSA model relies on two assumptions/conditions (our working assumptions):

- The firm exploits almost all its innovation through its own output;
- The firm does not innovate to grow rapidly (at the time of innovation).

In a nutshell, R&D would rise more than proportionally to sales in larger firms as they have more incentive to exploit their innovations chiefly through their own output and to do so at the time they conduct R&D. This implies that due to cost spreading, the consolidation of two or more firms can lead them to undertake R&D projects that were not previously profitable, thereby increasing the industry's rate of innovation (Cohen and Klepper, 1996, p. 947).

The second condition means that the firm expects that its innovation will diffuse among its current level of output or a closely related value of it. This is what Cohen and Klepper term as 'ex-ante output' or the output at the time the firm conducts R&D. The higher this output, then the greater the firm incentive to conduct R&D. The CSA also predicts that returns to R&D should depend more on firms size than if the firm could sell their innovation in disembodied form due to product innovation (Cohen and Klepper, p. 927): '… if firms could reap the full rents from their innovation via licensing, there would be no [CSA] of large size and (*ex ante*) firm size would not condition the returns to R&D.' (Cohen and Klepper, 1996, p. 947). These assumptions are the roots of the 'strong form' of the CSA hypothesis. As we work at the corporate level, we must focus on the prediction of the CSA model for this level of aggregation, which we call the 'weak form' of the CSA hypothesis. As noted by the authors, the prospect of appropriating a fraction of the returns of innovation obviously depend, among other things on patents application and the market structure, this latter being related to firm size.

The CSA Model and Electric Utilities

Testing the CSA is particularly difficult however, given the evolution of aggregated R&D efforts shown in Figure 1. Moreover, as suggested previously paragraph, changes in the market structure are likely to have influenced the appropriation of returns to innovation, an issue not explicitly modelled by Cohen and Klepper. More crucial, data limitation does not permit us to consider R&D at the level of business units. Therefore, if we find a close and positive (possibly more than proportional) relationship between R&D and size at the corporate level may not be evidence of the validity of the CSA hypothesis at the business unit level. Still, we believe the assumptions underlying their model are relevant for our understanding of the behaviour of electric utilities with respect to R&D effort, however.

By the CSA hypothesis, if there is a close relationship between R&D and size observed at the corporate level, it reflects an aggregation of such relationships at the business unit level. Other correlates of overall firm size can also account for that relationship at the corporate level (see Cohen and Klepper, 1996, p. 935–36; Symeonidis, 1996, p. 16). To mention a few, corporations have greater:

- Willingness to incur the risks associated with R&D (risk pooling);
- Access to finance (liquidity);
- Ability to internalise R&D spillovers due to greater diversification (scope economies);
- Likelihood to possess the complementary capabilities (e.g. marketing) necessary to exploit innovations.

Beyond the aforementioned correlates, the relationship between R&D and size should be strong in electricity for several reasons. First of all electricity research is very specific to the electric industry, with little scope for redeployment. Therefore, electric utilities have more incentives than firms from other industries to incorporate their process innovation in their own output.

Moreover, several incentives must have induced electric utilities to exploiting their innovation mainly through their own output rather than by selling them in disembodied form to competitors.[5] A first incentive is related to the high degree of concentration that we observe in the electricity industry. Over most of the period covered by our data several electric utilities were vertically integrated from generation to retail. Some were regional or national incumbents (a single or a few firms were enfranchised and deemed natural monopolies). Therefore, as incumbents they used to have a sort of pre-emption right on the use of innovations provided by domestic equipment builders. They feared less imitation from competitors, gained more scale economies associated with innovations (Horbach, 2008, p. 165) and the possibility of replication was restricted to the regional monopoly area of each utility. Second, for a homogenous good like electricity, the number of product markets is small (the good is essentially differentiated over time). This nature of electricity implies that electric utilities used to increase their margins in particular by reducing costs through process R&D.[6] The CSA model encompasses process R&D (see Cohen and Klepper, paragraph 2, p. 931) whose principal purpose is to lower the average cost of production of the firm's entire output. Unlike product R&D, process R&D should have as consequence that '… the expected returns to process innovation will be conditioned to some degree by the firm's ex ante output.' (Cohen and Klepper, 1996, p. 943).[7] The third incentive is an assumption at the heart of Cohen and Klepper's model thereby firms that have a CSA are granted with some market power over their products, which allows them to increase their margin once process innovation has reduced their cost of production. This is an appropriate assumption for electric utilities, the consumers of which have very high costs to switch them (see Salies 2008 and the references therein). Customers generally have high switching costs even several years after retails markets are opened up to competition, which makes incumbents willing to incur the risks associated with sunk R&D outlays. Electricité de France (hereafter, EdF) is a case in point given its position as ex-incumbent electricity retailer to almost 29 millions residential consumers. A fourth reason is that the incentive to increase margins by reducing costs is reinforced by the fact that retail electricity rates are heavily regulated (although to a lesser extent since the wave of electricity markets liberalisation). To put is briefly, rate regulation ensured some revenue to the firm, but induced it to raise margins through cost reduction. For example, in the case of the U.K., Littlechild (1998) clearly showed indeed the effect of price cap regulation such regulation in distribution businesses turnover and operating income: a tighter price control implies lower revenues.

The Formal Model

In the CSA model firms differ with respect to their R&D expenditures R_{ict} ($i = 1,...,N$ in country $c = 1,\ldots,C$ at year $t = 1,\ldots,T$). Given sales and other variables, all firms face the same price-cost margin schedule M_{ict} given by the following functional:

$$O_{ct}(1-1/\beta)^{-1}(R_{ict}^{1-1/\beta}-1) \tag{1}$$

where $R_{ict} > 0$, $\beta \geq 1$ and O_{ct} represents an index of industry technological opportunities, which affects firms of in country c equally and is allowed to vary over time. Therefore M_{ict} is an increasing but concave function of R_{ict} (process R&D in power plants diminishes production cost, regardless the level of consumer prices. The derivative of M_{ict} with respect to R_{ict} is what Cohen and Klepper (1996, p. 932) term as the marginal return from R&D (or marginal R&D productivity schedule). Firms are assumed to differ with respect to the productivity of their R&D efforts (as M is increasing in R , there is an advantage of being large as an innovator). When $1/\beta$ approaches 1, the l'Hôpital's rule leads to the margin schedule given in Cohen and Klepper (1996): $M_{ict} \to O_{ct}\ln(R_{ict})$ and the marginal R&D productivity schedule is equal to O_{ct} / R_{ict}. When $1/\beta < 1$ then the marginal R&D productivity schedule falls less rapidly than O_{ct} / R_{ict}. This is exactly the situation where R&D will rise more than proportionally with firm size, which will be reinforced in firms benefiting from higher O. Our CSA model is slightly more general than that of Cohen and Klepper (1996) in the sense that we explicited the price-cost margin functional in the case $1/\beta \neq 1$. There is also a difference with respect to Cohen and Klepper (1996)'s model in that in their paper, O is a fixed parameter. Here, O are country-specific to capture the influence of scientific capacity and the general propensity of countries to patent over time, in a single industry, namely electricity.

Let us denote Q_{ict} the level of output at the time the firm conducts its R&D. Cohen and Klepper assume firms earn rents from their R&D for one period that is the length of time before R&D is imitated, which they formalise as gQ_{ict} that is the fraction of output embodying the firm's innovation. Besides, since innovation does not influence current output they relate the amount of R&D to sales lagged one year.[8] Thus Q_{ict-1} is substituted for Q_{ict} in the theoretical model. Firm i chooses R_{ict} to privately maximise profits $M_{ict}(R_{ict})N_i\, gQ_{ict-1} - R_{ict} - F$, which we denote by Π_{ict} subject to the constraint that Π_{ict} is non-negative. N_i denotes the productivity level of firm i's R&D and F denotes a fixed cost required to carry out R&D programs. On introducing N_i, the authors allow smaller firms to

have greater R&D productivity to cover F, which accommodates departure from proportionality. Substituting (1) into Π_{ict} then maximising, one obtains the following expression for R&D:

$$R_{cit} = \begin{cases} (gO_{ct}N_i\,Q_{ict-1})^{\beta} & \text{if } \Pi_{ict} \geq 0 \\ 0 & \text{if } \Pi_{ict} < 0 \end{cases}. \tag{2}$$

Note that Eq. (2) which relates R&D expenditures of one firm only to its own output, its technical opportunities and returns to R&D implies electric utilities make 'independent R&D decisions'. The possibility that firms acquire another innovative one involved in complementary R&D activities is, perhaps, an argument against the independence assumption. I will look at the correlation structure of our model to test for the independence between all cross-section units over time.

THE DATA

Data on R&D and other variables of company's accounts listed below are from Thomson Financial (Datastream). We collected data on 22 major floated electric utilities operating mainly in Europe for the year 1980 through to 2007. We discarded equipment builders such as Areva and Alstom (France) or Siemens (Germany). This is left for future research (see our conclusion section). When several firms merged, we only consider the merged entity. Apart from Electrabel the acquisition of which by Suez is recent, affiliates are not considered as separate individuals in our sample. Furthermore, we focus on those particular firms that achieve a ratio of at least 50% of their sales in electricity in the year 2004 (see footnote 1 of Table 1). We therefore discarded British Gas, Gaz de France and Suez to avoid the consequence on our statistical results of heterogeneity across firms due to the presence of multi-utilities. Note this does not imply that the fraction of R&D expenditures devoted to electricity is at least 50%. Wilder and Stansell (1974) follow a similar approach to differentiate electric utility operations from other types of utility activities.[9] In their model, the ratio of electric to total operating revenue is inserted in the set of right-hand side variables. They avoided criticism of the lack of such ratio for R&D by presuming that revenues derived from activities such as gas distribution involve static technologies. In the present paper we were unable to find that ratio for all years of observation due to data limitation. Furthermore, this fraction has certainly changed over time as a result of acquisition of other firms.

Our panel is unbalanced for several obvious reasons. For example, some firms can be traced back longer than others. More crucial, there are missing values for the R&D variable with a few firms that never report R&D expenditures. For example, Iberdrola has missing R&D values from 1981 to 1990. We do not know whether this latter type of incompleteness is due to randomly missing observations. We are in the 'ignorable selection rule' as described in Baltagi (2005 p. 220). One obvious reason might be that certain firms refuse to report R&D, which should be controlled for. Another reason could be that according to their accounting standard some countries give firms the possibility to capitalise their R&D expenses, under certain conditions however (over most of the period covered in the present analysis, our firms were not subject to report R&D expenditures).

Firm's Characteristics

A brief discussion of innovation in the electricity sector shall be given in the following paragraphs,[10] with our choice of potential determinants of R&D in our sample of European electric utilities.

Electric utilities R&D

Our input innovation variable is total electric utilities R&D (their subsidiaries' R&D inclusive). It represents all direct and indirect costs related to the creation and development of new processes, techniques, applications and products with commercial possibilities. These costs can be categorized as basic research and applied research.[11] Electric utilities do not dedicate large sums to R&D (three out of our 22 utilities have no R&D expenditure and one firm reports only one value). They spend about 2% of their sales in R&D in the most favourable years (EdF, Edison, Enel, E.ON, International Power, RWE, Verbund), compared with equipment builders such as Areva (About 3.5%) and Vestas (2%). Compared to manufacturing firms in other industries (drugs and medical instruments, information and communication technologies, aircraft and aerospace), these figures are not big, neither for equipment manufacturers. A possible reason is that as we do not consider capitalised R&D expenses that are included in intangible assets (this is left for future researches), we may miss a significant fraction of realised R&D. More important, according to Deufeilley and Furtado (2000), the problem of electric utilities is that of adopting the right innovative technology, in particular in generation, than creating those technologies, which remains the role of equipment builders. As a consequence electric utilities dedicate fewer funds to researches that are more specific to equipment builders. This was conjectured by GAO (1996, p. 9) that suggested that electric equipment manufacturers may take on the development of new products.

The electricity industry as a whole favours the development of incremental technologies aimed at improving energy efficiency of existing plants from existing ones (small hydro plants, clean coal plants), notably in responses to movements in the price of energy resources (Defeuilley and Furtado, 2000, pp. 2–4). As amphasised by Jamasb and Pollitt (2008, p. 1005), '[g]iven the slow rate of growth in demand for electricity, it is less likely that utilities will engage in long-term and path breaking research'. As an example, researches on clean coal technologies (e.g. Topping Cycle technology in England and Wales) were neglected in favour of combined cycle-thermal gas plants during the period known as 'dash-for gas'. We notice political influence was a powerful driver for major innovations like the introduction of nuclear power (Markard et al., 2004, p. 210). Let us note that organisational innovations as well resulted from market liberalisation (Markard et al., 2004). Many electric utilities have for example undergone a phase of organisational restructuring, which includes the spin off of research units. As an example EdF Energies Nouvelles, 100% subsidiary of EdF corporation. As suggested in Markard et al. (2004), on founding subsidiaries to pursue a very progressive innovation strategy, the parent company can avoid frictions with the established business.

R&D in electricity can be split between environmental and non-environmental projects. We point out this distinction because as regards to the U.S. experience, it is environmental R&D that decreased significantly following electricity markets deregulation. According to many utility R&D

managers in the U.S.A., their companies shifted the focus of their R&D away from long-term advanced-technology R&D to short-term projects that would provide a competitive edge in the near term (GAO, 1996, p. 11). This paragraph also gives us an opportunity to be more explicit about R&D activity by electric utilities. Environmental R&D covers the full range of upstream and downstream issues relating to electricity. It is the R&D directed towards public-interest projects such as research on global warming. Environmental innovation in particular consists of new or modified processes, techniques, systems and products to avoid or reduce environmental damage (see Horbach, 2008, p. 163 and the references therein which suggest that it is difficult to agree on a definition of 'environmental innovation'). Long-term environmental researches are on micro-cogeneration, fuel cell batteries, tidal turbine system, new solar energy technologies, and biomass gasification. They also include researches on the local impact of climate change, biodiversity and water quality through studies on storage of radioactive wastes. From a short run perspective its aim is to make more efficient uses of energy, improve or develop coal plants with carbon dioxide capture, plants fed with renewable energy resources and energy saving appliances oriented towards small and large consumers, dispatching, smart network management to allow better integration of centralized generation and distributed energy, improving the performance of heat pumps (high temperature), electric vehicles and hybrid vehicles in partnership with the automotive industry.

Nonetheless, the distinction between environmental and non-environmental R&D is not trivial. Companies like EdF consider researches on future generation reactors as belonging to the former type.[12] Altough several R&D and test facilities have been closed in the past decade in Europe (WEC, 2007, pp. 79–80), France and other countries of the EU maintain active researches in nuclear fission (e.g. fast neutron reactor) and fusion both to meet more demanding safety criteria and maintain the EU's technological lead for a technology facing competition from the US and several far-Eastern countries.[13] In fact many big electric utilities conduct both types of researches. It is important to emphasise that unlike Sanyal (2007) who employs 'environmental R&D', we are unable to make that distinction over the period covered by our data (our sample spans 28 years).[14] Patents turn out to be more relevant a variable to overcome that problem (see the concluding section of the present paper).

Table 1 shows that apart from four out of 18 firms (British Energy, Endesa, Iberdrola Vattenfall), R&D intensity decreased following the first piece of legislation. Iberdrola increased its expenditure in R&D per € of assets size three years before the Spanish act in 1994 and three years after. No R&D data was reported since 1997 inclusive. The 46% increase in R&D

intensity of British Energy must be considered with caution as this firm reported R&D for only a three year-period, 2005–2007. Similarly, the drop of –53% of Verbund corresponds to a short period, 1998–2001. The evolution of R&D intensity for firms like EdF and E.ON is typical of results found in the literature: the change in R&D intensity is positive or small and negative before the first piece of legislation then it decreases significantly after (nearly –10% for EdF and –25% for E.ON). To show the significance of these results, it is important to emphasise that following the national energy acts, firms associated with a decrease in R&D intensity have also reduced the level of their R&D expenditures. There is one exception, namely SSE.

Table 1: Changes in R&D intensity before and after liberalisation

Firm	Share[1] Energy/Electricity	Year of first piece of legislation	ΔIntensity (%) before legilsation[2]	ΔIntensity (%) after legislation
Atel	100/100	2002	NV	NV
British E.	100/100	1989	NV	46.58
CEZ	100/92.6	2000	NV	–17.44
EdF	96/93	2000	29.48	–9.84
Edison	95/70.5	1999	–7.81	–28.63
EDP	95.5/90.7	1995	NV	NV
Electrabel	91/73[4]	1999	NV	0[5]
Endesa	98.6/95	1994	NV	27.89
Enel	82/69	1999	1.30	–18.78
E.ON	97.8/55	1998	–2.05	–24.47
Iberdrola	95.7/92	1994	17.00	10.57
Inter. Power	NA[3]	1989	NV	–13.59
MVV Energie	95/52[4]	1998	NV	–12.38
RWE	82.6/56	1998	–0.96	–19.78
SSE	95/70	1989	NV	–1.01
U. Fenosa	86.4/80.9	1994	NV	NV
Vattenfall	93.4/87.2	1995	NV	49.59
Verbund	98.5/98.5	1998	NV	–53.08

Note.

1. For some firms, the column includes the share of electricity in total sales in 2004 (Eurostaf, 2005, p. 81). We consider firms whose the share of electricity in total sales or revenues is at least 50%. For firms not present in the 2005's Eurostaf document, we checked directly in Datastream. The year is that previous merger operation. When Datastream reports that the firm operates in the 'electricity sector' but the share of electricity dales in total sales is not available we went to visit firms' corporate website. We retain firms whose annual report in 2007 explicitly mentions that most sales are derived from owning and operating power plants.
2. The date of liberalisation varies across countries, but is not reported here.
3. 'NA' stands for 'Not Available' but we know from the firm's annual report that most firm's sales are derived from owning and operating power plants corporate
4. Figures for Electrabel and MVV Energie are observed in 2005 and 2008, respectively.
5. '0' means the firm reported one value for R&D. An empty cell means that there was no R&D data reported for that period.

Size

The choice between sales and assets as a proxy of size is not obvious, more particularly in the energy sector. Wilder and Stansell (1974) and Sanyal and Cohen (2008) employ annual total utility operating revenues as the size variable whilst Dhrymes and Kurz (1964) used sales. As in Sanyal (2007) we use total assets. Del Monte and Papagni (2003) recommended using sales as a proxy for size, for it as has merit to avoid problems over capital valuation during periods of inflation, of revaluation. On the one hand, changes in the price of fossil fuels may be responsible of significant changes in sales through changes in the wholesale price of electricity. This may reinforce the potential endogeneity of sales as a size variable. For these reasons, we prefer to use assets.[15]

Network activities

A distinction between firms owning regulated networks and others is important as shown in Bourgade (2008) from a sample of firms operating in electricity. It is crucial to differentiate electric utilities with respect to network business owning, for price regulation of network activities provide vertically integrated utilities with highly predictable and recurrent cash-flows (Bourgade, 2008, p. 2): revenues from distribution are partially guaranteed as regulators control distribution prices which are typically set a year ahead. As a consequence the acquisition of distribution businesses can be more attractive than acquisition of generation assets since revenues from generation activities fluctuate with the intensity of competition and the volatility of price energy resources thus the less productive firms may experience some punctual losses when retail rates are caped low. Whereas supply activities will have to face lower profitability for firms exposed to CO_2 prices and emission schemes (Bourgade, 2008), cash-flows related to network activities brings stable revenues which could be used to fund R&D projects. Furthermore, littlechild (1998, pp. 20, 24) showed evidence for Great Britain that operating profits in distribution was ten times higher than in retail.

A dummy for the existence of network activities will be inserted. The expected influence of the 'network' dummy variable is ambiguous, however. Network activities are a source of predictable cash flows likely to finance innovation in vertically integrated utilities, certainly, but network businesses have less incentive to spend in environmental R&D than supply businesses. Sanyal (2007) does not consider electricity distributors as innovators compared to power producers and equipment builders. Unlike generators and retailers, network businesses do not contract directly with consumers thus have little scope to competing for consumers outside their local network. In fact, they are more the subject of acquisitions by other firms.

M&A operations

The issue here is whether for those firms that acquired others, innovating activities are different. We remind the reader that we selected firms that have not been subject to acquisitions by others. Therefore, financial reports of all firms are available until 2007 that is the latest year in our sample. One exception is Electrabel, the financial report of which dropped in 2007. M&A operations is a favourable event to test for the Schumpeterian hypothesis as they have as systematic effect to increase the size and impact several variables of the balance sheet. They may therefore have a positive effect on internal R&D in regards to the CSA model as the output over which to spread the cost of R&D increases. M&A operations can also influence positively the amount spent in R&D, for merged entities find complementarities in research outputs that are favourable to each individually (technological transfer,…). They would increase their control over the diffusion and use of their innovation. On the other hand intense domestic and more particularly cross-border mergers operations can have as effect to reduce the variety in innovative activities by electric utilities (Markard et al., 2004, p. 212). M&A operations can indeed be motivated by the acquisition of external technical knowledge, or firms would acquire others to substitute these latter's R&D s skills for their own (Bertrand and Zuniga, 2006; Brouwer and Kleinknecht, 1996, p. 193), so that M&A operations influence negatively the amount of R&D per unit of size.

Sanyal and Cohen (2008, pp. 25, 46) controlled for pending mergers through a dummy that takes the value 1 from the time mergers are announced till the date they are consumed and found a negative influence on R&D. We choose a different approach. Given R&D reorganisation requires time, to test the hypothesis that mergers reduce duplication of R&D expenditures (the coefficient multiplying the M&A variable should be negative or zero), we follow Bertrand and Zuniga (2006) who used as a measure of M&A intensity the past cumulated number of M&A over a period of three years with a year lag to account for the delayed repercussion of industrial restructuring on R&D. The different kind of operations (full purchase, merger and increase in shareholding) are not distinguished. Thus a non-significant coefficient could reflect the aforementioned opposite influences.

Financial policy

Little is known about the link between electric utilities' corporate financial policy and R&D funding in the economic literature. There are at least two reasons. Papers that address this issue did it for U.S. electric utilities and without going into details (Sanyal, 2007 and Guerard, 2005 who report the study on electric utilities of a famous 1958's Modigliani and Miller paper; Wilder and Stansell, 1974). Other works on electric utilities' finance did not consider R&D (Blacconière et al., 2000; Dhrymes and Kurz, 1964). Recent acquisitions by European electric utilities however suggest these firms are willing to use a large portion of their financial resources for foreign investment, notably cross-boarder acquisitions and purchases of shares in companies' stock. In fact, acquisitions can increase debt to such an extent that The Financial Times reported recently financial analysts were expecting EdF to be cash-flow negative at the operating level in 2009 and 2010 (Hollinger, 2009).

The financial policy of electric utilities. Wilder and Stansell (1974) and Sanyal (2007) considered a profitability variable among the determinants of R&D. The usual argument about the profitability-R&D link is if firm margins rise, then managers become more optimistic about their firms' fate and raise R&D spending (Mahlich and Roediger-Schluga, 2006, p 154). Though, Wilder and Stansell found an inelastic response of R&D suggesting that an increase in the regulated rate of return would not be an effective way to increase utility R&D outlays. At the converse, Sanyal found a strong positive impact which she interpreted as electric utilities with more spare resources spend more in environmental R&D. These opposite results, notwithstanding they relate to different sample periods, do now allow us to predict the expected effect of profitability on R&D for European electric utilities.

Related papers on the financial policy of electric utilities are that of Dhrymes and Kurz (1964) who considered the determinants of the dividend policy of electric utilities before the U.S. electricity industry was deregulated, and Blacconière et al. (2000) who considered the role of deregulation on the value relevance of earnings. Dhrymes and Kurz found that payout ratios were characterised by a considerable degree of inertia with significant differences across firms, however. They interpreted a significantly positive influence of sales on the payout ratio and on dividends per dollar of sales as evidence that small electric utilities tend to retain a higher portion of their profits (distribute less dividends) than the larger ones. From this and other results they suggested as an explanation that size is also an indication of ease of access to the capital market with smaller firms that are 'compelled' to finance a relatively larger portion of their investment program by internal means. Blacconière et al. found that U.S. electric utilities were more able to earn abnormal rents (or incur abnormal losses) following deregulation in 1992 (the U.S. Energy Act). As mentioned previously, under rate regulation, utility shareholders are virtually assured a rate of return on 'stranded assets'.[16] In a deregulated environment, the eventual recovery of these costs depends more closely on future prices of energy, regulatory interventions (Blacconière et al., 2000, p. 238) and perhaps the toughness of competition policies. The main reason that is also their main conclusion is that earnings have become more important in the valuation of electric utilities (Blacconière et al., 2000, p. 234). Unlike a sample of capital intensive firms in manufacturing (used as control group), the value of electric utilities' earnings became more relevant than book value. They also found results consistent with utilities being valued differently than non-utilities prior to deregulation and more similarly to non-utilities following deregulation (Blacconière et al., 2000, p. 247).

Given the small number of papers about the influence of financial policy on R&D funding by European electric utilities, we find logical to draw on studies about the interdependencies of financial policy and R&D efforts outside the electricity industry. Initially, we briefly review recent empirical papers on R&D funding by small and large firms in manufacturing, before turning to the peculiarities of electric utilities with regards to financial constraint. Then we list the financial policy variables considered for our sample of electric utilities.

R&D and financial policy in manufacturing. A way to consider the role of financial policy on R&D funding is through testing for the presence of liquidity constraints, or excess sensitivity to cash-flow shocks that are not signals of future demand increases. This literature has mainly looked at the cost implication of debt versus equity financing (Casson et al., 2008, p. 210). If a firm uses some of its additional cash for R&D, then it is said to be financially constrained in the sense that it must have had some unexploited investment opportunities that were not profitable using more costly external finance (Hall, 2002, pp. 41–43). Empirical evidence typically shows a positive association between R&D spending and cash flow, indicating a gap between the external and the internal costs of capital (Mahlich and Roediger-Schluga, 2006, p 147). However debt is usually serviced from cash flow (debt requires a stable source of cash flow), which reduces the amount available to sustain a productive R&D programme. This literature also concludes however that the existence of financial constraints on innovation decreases with firm size, and depends on sectors. But the use of cash flow can be misleading. Mohnen et al. (2008) report a study where cash flow was not informative about the flow of R&D for panels of UK and German firms. There is also some agreement in the literature that cash flow sensitivity of investments need not identify liquidity constraints but rather is indicative of high demand and expectations of future profits (see Mohnen et al., 2008; Musso and Schiavo, 2007). As a consequence, we can't be sure whether the absence of a significant relationship between R&D and cash flows is indicative of an absence of financial constraints. To overcome that problem we will insert real GDP per capita in our regression equations to isolate cash-flow shocks that are not signals of future demand increases (see our paragraph on countries' characteristics).

The relationship between financial policy and R&D is also studied through the role of dividend policies in imperfect markets. In perfect financial markets R&D decisions should be independent of the firm's financing decision. New debt is issued to finance R&D while new capital issues raise funds from which R&D is undertaken too. The existence of a negative relationship between R&D expenditures and dividend paid is a standard result of the hypothesis of imperfect financial market. 'Given that dividends and investment are alternative uses of funds, as dividends increase is an imperfect market one would expect investment to fall.' (Guerard et al., 1987, p. 1421). Guerard et al. find evidence of this as the effect of dividends on R&D is either non-significant or significantly negative in a sample of manufacturing firms in the U.S.A., which suggests that research is an alternative use of funds to paying dividends.

It also turns out from this literature that R&D-intensive firms use a different financial policy to fund R&D projects. In a panel excluding utilities, Bah and Dumontier (2001, p. 675) suggest that non-R&D intensive firms (firms which exhibit an R&D-to-sales ratio lower than 5% in their paper) should exhibit a higher dividend payments and lower proportion of cash than R&D-intensive firms. R&D-intensive firms on the other hand prefer equity financing/short term debts and less dividend payments/more cash reserves to finance their R&D investments. For a panel of large and medium-sized firms in the U.K., Casson et al. (2008, pp. 215–7) find that '[f]irms with positive R&D tend to use more debt [(total debt as a share of total assets)] than firms with zero R&D, but among the R&D performing sub-sample the use of debt declines with R&D intensity.' This is consistent with firms that report positive but low R&D use more debt finance than firms that report no R&D. Hall (2002, p. 40) also emphasises that large firms do prefer internal funds for financing investment in R&D while small and start-up R&D-intensive firms are either unable or reluctant to use debt finance for R&D investment.

A general conclusion from this literature is that most R&D is funded internally as markets for financing R&D tend to be incomplete (investors outside the firm have difficulty distinguishing good projects from bad when the projects are long-term R&D investment. A corollary to that statement is that if firms have ready access to relatively cheap and long-term external funds, then R&D investment decisions is less dependent on internally generated cash flow (Mahlich and Roediger-Schluga, 2006, pp 152–3; Hall, 2002, p. 38). Casson et al. (2008, p. 211) summarise the debt-equity tradeoffs by asserting that 'Although firms may prefer internal funding … [they] are faced with fluctuations in profitability and have dividend policies with target dividend payout ratios, limiting the availability of funds for investment. In doing so, debt is the preferred form.'

Given the limited number of papers on the R&D-financial policy by electric utilities and since these latter have their own peculiarities, it is important to emphasise some of their characteristics that guided our choice of financial variables.

The peculiarities of electric utilities in regard to financial constraint. Firstly, it is important to highlight the influence of regulation and deregulation. We previously provided elements which suggest that financial policy may have changed following the deregulation of electricity markets. In this respect Dhrymes and Kurz (1964, p. 81) asserted how delicate is undertaking a statistical study of the financial policy of electric utilities, '… since there are many *semipolitical* factors that enter into the decision making and since differences in the controlling power of local regulatory commissions may affect the financial policy of the firms.' Rate regulation, which protects the firm against the risk of large losses, plays certainly a role but also denies above normal profits which could result from innovative activity (wilder and Stansell, 1974, p. 647). Above all, the essential role played by the electricity industry in the growth of nations is such that investments by electric utilities were largely oriented by governments' energy policies, more particularly before the deregulation of electricity markets. Note as well a low 'investability' (or openness to foreign equity investors) of many European electric utilities: state-controlled electric utilities like EdF (85% belongs to the French state) may not have the freedom to call on shareholders for more funds, which stretches their financial flexibility.

The liberalisation of electricity markets has, as expected by electric utilities themselves (GAO, 1996), induced higher requirements on return on capital (WEC, 2007, p. 65). Markard et al. (2004), for example, conducted an empirical survey which revealed the minor role played by financial returns in electric utilities before markets liberalisation in Germany, The Netherlands and Switzerland. Since financial requirements are becoming high in the business of electric utilities, it has also been suggested (Bourgade, 2008, p. 2) that a favourable financial profile will stand as a valuable and competitive asset for some firms, in particular where the categorisation of certain liabilities is at stakes: 'Moderately leveraged firms, with solid debt servicing ratios can better benefit from profitable growth opportunities than firms suffering from more aggressive financial profiles,…'. As electric utilities started being privatised and engaged in cross-boarder mergers with other utilities, the role of financial policy as a signal to investors became more crucial (see our previous discussion on the higher relevance of earnings in the valuation of electric utilities). Electric utilities would tend to resemble smaller, not established firms in manufacturing to which retained earnings in the R&D investment decision plays an important role, independent of their value as a signal of future profitability (Hall, 2002, p. 41). It is thus expected that positive cash flow (internal finance) play an increasing role for R&D than for ordinary investment.

In addition to the differential effect of changes in market structure due to the reforms, the slow turnover of physical assets and the specificity of power plants should be another key factor behind the choice of financial policy by electric utilities. Indeed, the long-term is the timeframe that should be used to judge electric utilities more particularly in the nuclear sector (Hollinger, 2009). Though R&D expenses can reduce short-term profitability, they are viewed as a long-run investment, more particularly for upstream firms where the turnover time for current power generation infrastructure is slow (Margolis and Kammen, 1999). This long-run nature of investments is likely to favour debt financing of R&D projects. Bourgade (2008, p. 13) also concludes that the structure of liabilities is not a key determinant of firms market capitalisation, which reflects the long term nature of investment projects in the electric industry too.

In addition to the stability or increases of cash flows, the composition of electric utilities' assets should be a main factor influencing their financial structure. Hall (2002) reports that banks and debt-holders prefer to use physical assets to secure loans and are reluctant to lend when the project involves substantial R&D investment rather than investment in plant and equipment. On the other hand, assets that are not very redeployable are less suited to the governance structures associated with debt (asset specificity à la O. Williamson). Electric utilities are a case in point; they invest in large, capital-intensive production plants that have very few alternative uses (see Jolink and Niesten, 2008). But, non-redeployment is precisely a characteristic of R&D-intensive firms who invest in highly specialised researches. Electric utilities are not R&D-intensive, however as we already showed. These seemingly contradictory results suggest that electric utilities' financial policy could be similar to that of both R&D-intensive firms and non R&D-intensive firms (e.g. in manufacturing) in particular as regards indebtedness. Our opinion is that as most electric utilities are still regional or national incumbents, clearly protected against bankruptcy, they enjoy a particular situation which enables them to carry a high proportion of liabilities.

We shall now list the variables we considered to control for the influence of financial policy on R&D funding by electric utilities. As in Bah and Dumontier (2001) we name these variables by using the Thomson Financial's Worldscope numerical classification. This will help comparison with future research on the role of corporate financial policy on electric utilities' R&D funding. We also use some abbreviations used in the financial economics literature.

Electric utilities' financial variables. To measure indebtedness we use long term debts (3251). Regarding profitability, we follow Bah and Dumontier (2001) and Wilder and Stansell (1974) who use returns on equity that is earnings before extraordinary items (1551) divided by total equity (3501), a ratio known as ROE. Note that Sanyal (2007) uses the so called EBITDA divided by total assets. We use one measure of dividend policy, namely the total common and preferred dividends paid to shareholders of the company (4551). Finally, for our measure of budget constraints we use one measure of the level of cash at the disposal of the firm (2001). If the coefficient multiplying the cash flow variable is not significantly different from zero then firms are not subject to any external financial constraint whilst if it is significantly positive, the firm faces some contraint (see Mahlich and Roediger-Schluga, 2006, for an application to the pharmaceutical industry).

Country's Characteristics

We follow Sanyal (2007) and use country level data to capture market structure changes due to restructuring and the pace of deregulation. Besides, as a corporate may be located in or have its main activities in a geographical area which may be more or less conducive of innovation, we control for the possible contributions of upstream suppliers' innovation and the general influence on R&D decisions of national propensities to innovate. Furthermore, we control for the mix in generation capacities held by electric utilities. We motivate the choice of these three factors in the following paragraphs.

Deregulation and competition

As suggested in the literature, institutional changes (deregulation, full market liberalisation) are of importance on R&D efforts, more particularly as regards electricity generation where competition often is greatest. Since a fraction of R&D is connected to generation activity, the divesture of generation assets that generally follows market deregulation should have a negative impact on R&D. As suggested by Jolink and Niesten (2008), 'The unbundling and the introduction of competition into the industry have increased the importance of the dedicated investments [henceforth R&D] and uncertainty for the electricity generators as they have lost their relatively stable customer base'. For example, vertical integration provided a safeguard for the generators against opportunism by the network operators. The link between upward competition and technology development was emphasised even earlier by the International Energy Agency (Sheer, 1996, p. 9). According to the Agency,

> As generators are unsure of which customers they will be servicing at the expiration of short-term generation contracts, there is little or no incentive for them to engage in R&D efforts which aim to reduce the cost or raise the efficiency of generating technologies over the long-term, even where there would be clear … benefits for society.

It would be interesting to use some annual values of a concentration variable at the firm level. Unfortunately, generation data at the firm level is not available over the whole period covered in the present analysis. More important, such a variable is not appropriate because electric utilities were not competing for market shares abroad before market liberalisation which occurred at different dates across countries. Differences in the configuration of the electricity industry at the time of market liberalisation across countries could also be of importance. As an example, in England, as more firms started competing at the time where regions opened up to entry of firms from foreign regions and foreign countries, potential competition was subsequently higher. But for a similar reason than that just given, changes in the number of players is available and only partially since the deregulation of electricity markets. A further interesting variable is the toughness of price regulation over time. We have only found that variable for European electric utilities for the year 2005, however. In the case where a more complete variable would be available, it would be necessary to isolate an unregulated control group in the industry to see the particular effect of price regulation. But, all our firms were subject to rate or revenue regulation for most of the years spanned by our data. This problem is similar to that in wilder and Stansell (1974) whose sample included more than 90% of regulated firms thus could not find a net effect of regulation on R&D outlays.

For these reasons, we capture the effect on R&D of deregulation and competition through a variable that takes a value equal to 1 since the year of the first piece of legislation, and a variable that measures the number of years since countries fully opened their retail markets to competition. The choice of the former variable is motivated by the work of Sanyal (2007) who found that passing an order for retail competition has more effect on *environmental* research than implementing legislation for retail access. That variable also captures the change from regulated to deregulated utilities. It is an appealing candidate to capture the trend reversion that we observed in R&D. Nonetheless, it is important to allow for a differential effect of deregulation and competition, which motivates our choice of a potential 'retail competition effect'. We do not use the same variable than in Sanyal (2007) who classifies U.S. states according to the stage of deregulation they reached in 1996 (the year that showed wide spread deregulation activity). We assume that that variable, the value of which can vary across firms but is constant over time for each firm, should capture similar influence than the variables used in Sanyal (2007), however: we expect the later the year of retail market opening, the lower should be the decrease in R&D.

Technological opportunities

In addition to our previous variables, we include a variable of technological opportunities to control for differences between firms with respect to their propensity to patent the results of inventive activity (we borrow this idea from Johnstone et al., 2008; see p. 5 of their paper). The rationale behind this assertion can also be found in details in Nelson and Wolf (1997, p. 207) who assert that the richer the technological opportunities, the more R&D it is profitable for firms to fund (efforts in R&D are more productive). We follow Johnstone et al. (2008) who capture differences in both scientific capacity and the propensity to patent across countries and time through the use of patent applications to the European Patent Office by priority year at the national level divided by nominal gross domestic product. This variable is influenced by national innovation policies and cultural factors. It may also capture differences in environmental regulation due to difference in environmental policy instruments which unfortunately are not available over the entire period covered by our data set. This variable is also a rough measure for the contributions of upstream suppliers' innovation which is made by equipment and research equipment suppliers from industries outside electricity (chemistry, metallurgy, mechanical engineering, physics …).

Technological opportunities should be positively related to R&D efforts, for at least two reasons. It is expected that a firm in a country with a persistent higher level of technological opportunities than that in other countries, will benefit from higher R&D spillovers. Second, as this variable takes values that also change over time, in countries with increasing technological opportunities, R&D at the level of firms should increase too. Obviously as Nelson and Wolf (1997, p. 213) point out, R&D done upstream can pre-empt or be a substitute for R&D in the electricity industry (the more of the work that is done upstream, the less is done in-house), thus diminishing the role played by this variable.[17]

Fuel mix

The consideration of the fuel mix in each country is motivated by the work of Sanyal (2007) who finds a positive influence of a 'coal heavy state dummy' on environmental R&D spending. This is supported by the study of Markard et al. (2004) at the firm level that shows evidence that in case of green power, existing resources and assets like hydro power plants '... represented a strong incentive to launch a green power product whereas a long tradition in nuclear or fossil fuel based power generation rather represented a barrier.' It is therefore likely that in firms like EdF, which produces electricity essentially from nuclear and hydro plants, these variables will have opposite effects on R&D. We can't use the share of coal at the firm level, due to data limitation. We use a time-varying variable that is available at the country level from the International Energy Agency, namely the share of conventional net thermal generation (electricity generated from oil, coal and gas) of country c in year t divided by net generation in that year from hydro and renewable resources (net generation excludes the energy consumed by the generating units).

Demand side factor

We finally consider proxies for growth opportunities. P. Sanyal uses gross state product to see if richer states conduct more environmental research, asserting that '… environmental preferences and ability to take collective actions is greater in richer areas than poorer ones and this translates into differential environmental strategies adopted by [electric utilities]…' (Sanyal, 2007, p. 349). Our variable is gross domestic product (GDP hereafter), at market price per capita. We thus expect that that variable will have a positive effect on R&D.

Currencies from countries outside the European Monetary Union were converted to euro. R&D, Size, GDP and other monetary variables are measured in real term by using the GDP deflator. The data on national patent applications to the European Patent Office by priority year are from the Eurostat webstite. The variable of patent applications at the level of the firm were collected from the European Patent Office's Espace Access data base. Finally, information on M&A operations are from Lévêque and Monturus (2008). We checked and completed them by using other online-resources.

THE ECONOMETRIC MODEL AND RESULTS

The Model Specification

Unlike Cohen and Klepper (1996) we estimate the multiplicative form of marginal returns to R&D schedule, which will invole taking the logarithm of the variables:

$$R_{ict} = (gO_{ct}N_{it,s}Q_{ict-1})^{\beta}e^{V_{it}} \quad (3)$$

We take the Napier logarithm of Eq. 3, which gives:

$$\ln R_{ict} = \beta_1 + \beta\ \ln(O_{ct}) + \beta\ \ln(N_{it,s}) + \beta\ \ln Q_{ict-1} + V_{it} \quad (4)$$

where $\beta_1 \equiv \beta \ln g$. Throughout productivity $N_{it,s}$ is approximated by corporate past growth rate:

$$(Q_{ict} / Q_{ics})^{1/(t-s)},\ s < t. \quad (5)$$

where unlike t, s is fixed. Since accounting data are available later than 1980 for some firms, we start with a value for s such that $s = \min\{1990, t : Q_{ict} > 0\}$. Note that unlike Cohen and Klepper (1996), we consider neither technological opportunities nor R&D productivity as fixed parameters.[18] Therefore there is no reason why the coefficients multiplying these variable should take the same value in the population. Besides, they must be sensitive to the proxy we choose for measuring technological opportunities (O_{ct}) and the proxy for productivity ($N_{it,s}$).We thus relax the constrain on the β s in (4) and offer a more general specification including firm-effects and our control variables stacked in the vector $\boldsymbol{x}_{ict}$:

$$\ln R_{ict} = \beta_1 + \beta_2 \ln Q_{ict} + \beta_3 \ln(O_{ct}) + \beta_4 \ln(N_{it,s}) + \boldsymbol{x}_{ict}{}' \boldsymbol{\beta}_5 + \sum_{j=1}^{N} \mathrm{M}_j d_{ij} + W_{it} \quad (6)$$

where $d_{ij} = 1$ if $j = i$ and 0 otherwise, $r_{i,t-s}$ is the average exponential growth rate of sales for firm i and period $[s,t]$ (when this rate is small, $\ln(N_{it,s}) \cong r_{i,t-s}$), and V_{it} contains the firm-specific effects plus an error term W_{it} .

The Results

As in many of the empirical studies of the R&D-firm size relationship, we employ data at the corporate level. Unlike Cohen and Klepper (1996 p. 937), it is thus impossible to test for the effect of corporate size on business unit R&D and therefore the 'strong' from of the CSA hypothesis can not be tested (see Cohen and Klepper, 1996, p. 936). However, when aggregated across firms the existence of a proportional R&D-firm size relationship at the level of business units must produce a close relationship between corporate R&D and corporate sales. The analysis of the CSA hypothesis at the business unit for electric utilities is left for future research.[19] Our main hypothesis (the 'weak' from of the CSA) is $H_0^1 : \beta_2 \leq 1$, against $H_1^1 : \beta_2 > 1$. If the null is rejected, or the estimate of β_2 is greater than one, this will lead to acceptance of the Schumpeterian hypothesis and rejection of the threshold side hypothesis.

As in Sanyal (2007) our objective is to estimate a random effect model which would be an appropriate way of proceeding here as our sample in hand may not be sufficiently representative of the underlying population. Our sample is indeed drawn from of a larger population that includes more than two hundred firms including multiutilities which have significant activities in electricity, and we did not considered separately the affiliates from our firms. There are three other crucial issues we have to address before we start to provide estimates for the coefficient of the variables supposed to determine R&D. One is related to the *poolability* of the data, the second is the *endogeneity* of size over our sample period, and the third is *sample selection*.

Poolability

We use the Roy-Zellner version of the test for poolability. Given that the number of variables of our model approaches that of firms we restricted the model by excluding the control variables ($\boldsymbol{x}_{ict}$) to avoid collinearity between a subset of the regressors. The model is estimated with random-firm effects by using the Swamy-Arora estimator (see Vaona, 2008; Baltagi, 2005, p. 70).

It includes our three explanatory variables plus their interaction with firm dummies. The model estimation is not very satisfying due to the collinearity problem which forces us to drop some interaction variables. The test statistic is equal to 194.25 that is distributed as a $\chi^2(32) = 46.19$ which leads to rejection of the null of poolability.

The first column in Table 2 reports results for the basic model. From this model, the Student statistics associated with $H_0^1 : \beta_2 \leq 1$ is 0.639 that is lower than the 5 or 10% critical value thus we reject the hypothesis from this model. As we shall show, this model specification is too simple and omits several of the key variables introduced in the previous section.

Table 2: The basic model

	Model 1		Model 2	
Size	1.064	***	1.159	***
	(.100)		(.095)	
Productivity	–4.471	***	–2.412	***
	(1.536)		(0.537)	
Tech. Opportunity	0.073	*	0.126	***
	(0.042)		(0.044)	
Constant	–7.523	***	–9.931	***
	(1.885)		(1.684)	
No. observations	104		59	
R^2 overall	0.69		0.73	

Note: The models have firm-random effects. The coefficients are estimated by GLS. Standard errors are robust. '***', '**', '*' denote significance at the 1%, 5% and 10% level, respectively.* Model 1 assumes $s = 1990$ in the formula for $N_{i,t-s}$ whilst $s = 1998$ in Model 2.

Endogeneity

As we already emphasised firm's size is more likely to respond to domestic electricity demand, due to obligation of services. Therefore, size is likely to be exogenous. As emphasised by Cohen and Klepper (1996, footnote 26, p. 939) however, 'R&D is expected to affect growth with a considerable lag due to the time it takes to generate, develop and commercialise innovations'. But, our sample period covers 28 years, which is exactly the situation in which we should care about a possible effect of R&D on Size, an issue not addressed in Sanyal and Cohen (2008) and Sanyal (2007).

Cohen and Klepper (1996) suggested an indirect test of this endogeneity bias, which consists in checking if different values for s in $N_{it,s}$ affect significantly the result of the overall model estimation. We thus test for the possibility that R&D determines firm's size by varying s in $N_{it,s}$. We compare the previous result with $s = \min\{1998, t : Q_{ict} > 0\}$. The model is reported in the second column of Table 2. The coefficients seem to change significantly for both size and productivity, showing evidence of endogeneity.

Table 3: Full model

	Model 3		Model 4		Model 5	
Size	1.538	***	2.083	***	2.249	***
	(0.508)		(0.324)		(0.210)	
Productivity	2.324	*	0.876		0.132	
	(1.372)		(1.107)		(0.764)	
Tech. Opportunity	0.093					
	(0.149)					
Distribution Network	dropped					
M&A	0.825					
	(0.068)					
Debt	–0.525	***	–0.715	***	–0.765	***
	(0.174)		(0.130)		(0.117)	
Cash	0.119					
	(0.132)					
Profitability (ROE)	–0.114					
	(0.299)					
Dividend	-6.35×10^{-7}	***	-4.18×10^{-7}	***	-4.10×10^{-7}	***
	(1.75×10^{-7})		(1.16×10^{-7})		(1.08×10^{-7})	
Electricity Act	–0.569	**	–0.211		–0.337	**
	(0.279)		(0.191)		(0.169)	
Retail liberalisation	dropped					
Fuel Mix	0.120	***	0.078	***	0.058	***
	(0.032)		(0.021)		(0.017)	
GDP	1.586					
	(1.098)					
Constant	–26.178	***	–15.720		–17.478	***
	(11.169)		(4.690)		(2.827)	
Inverse Mills Ratio			1.809	***	1.895	***
			(0.317)		(0.283)	
No. observations	108		126		292	
R^2 overall	0.28		0.55			

Note:. '***', '**', '*' denote significance at the 1%, 5% and 10% level, respectively. 'Model 3' has fixed-firm effects. The coefficients are estimated by OLS. A test for the equality of the fixed effects produces a *f*-statistics of 5.11 that is greater than the tabulated value (≅1.8). 'Model 4' has fixed-firm effects corrected from sample selection. The hypothesis for the equality of the fixed effects is also rejected in this model. 'Model 5' is a tobit with left-censoring at zero. To scale the results, the model includes a dummy that is equal to one for each observation associated with a zero R&D value.

Note that the number of observations is reduced dramatically due to the restriction imposed on the productivity variable. Besides, the sub-period from which we estimate the model corresponds to the deregulation of the electricity industry in several countries, with an average of 5 years per firm. The coefficient estimates are thus less subject to the trend reversion in R&D. From this model, the Student statistics associated with $H_0^1: \beta_2 \leq 1$ is 1.670 that is nearly equal to the 5% critical value (1.67) and greater than the 10%

critical value of 1.9. We thus reject the hypothesis of an advantage of small firms in R&D in favour of the Schumpeterian hypothesis. We also ran the classical Hausman procedure to test for exogeneity of the size variable in the panel from the results of a model with firm-fixed effects.

Since endogeneity was detected with the previous procedure, we decide to include all the variables presented in the previous section as this omission may be the source of the endogeneity problem. To have a larger sample size as possible, for each firm we use $s = \min\{1980, t : Q_{ict} > 0\}$. The test statistic is equal to 52.40 that is distributed as a $\chi^2(10) = 18.31$ which leads to rejection of the null hypothesis and also to adoption of the model with firm-fixed effects. The results for the estimated coefficients of this model are reported in the first column of Table 3. The coefficient on 'Productivity' is more consistent with the predictions of the CSA model and results found elsewhere in the literature: '… the larger the past growth rate of the firm … then the greater the future output of the firm over which it can apply its R&D, thereby providing it with a greater incentive to conduct R&D' (Cohen and Klepper, 1996, footnote 35, p. 942). Although the estimated coefficient on the size variable takes a larger value than in the previous model, its precision has reduced. The problem here is that of sample size bias.

Before interpreting the results we must try to overcome the loss of degrees of freedom due to the large number of reported zero R&D values. A quick-and-easy way would be to estimate a Tobit model with left censoring. In fact, in our case, with nearly 68% missing empty R&D observations, the Tobit is definitely justified. Following Sanyal (2007) we try first to find evidence of sample selection.

Sample selection

Sanyal (2007) uses a random effect Tobit specification with the lower bound at zero since she did not find evidence of selection. Sanyal and Cohen (2008) find evidence of selection, however.[20] The rationale for sample selection is justified as follows. Our R&D (dependent) variable contains a considerable amount of zeros, however. For example Union Fenosa, does not report R&D at all. It is difficult to know whether no reporting of R&D is a randomly missing process or an endogenous decision (see Bound et al., 1984, pp. 22–25): 'An important issue is whether the fact that [some] firms do not report R&D expenditure will bias results based only on firms which do.' Sanyal and Cohen (2008) and Sanyal (2007) formulated the problem of sample selection as one where electric utilities' investment in R&D is a two-step process. First, electric utility i decides whether it invests in R&D or not in year t, a decision which depends on the firm's expected future benefits from R&D. If this latter expectation is above some threshold then it decides the amount it wants to spend (the structure of the formal econometric model can be found in Sanyal and Cohen, 2008).

This approach is consistent with the condition that the profit maximising level must be non-negative (see Eq. (2)), which en passant suggests that the firm's profit can be considered as a selection variable. It turns out that this description relies on accounting practices in the U.S.A where firms must expense R&D as it is incurred (capitalization is not allowed in the USA with a few exceptions; see Oswald et Zarowin, 2007) whereas in Europe, companies have more discretion regarding the possibility to capitalise their R&D expenses. We must therefore admit that as some if not all of our firms have the choice to expense or capitalise their R&D efforts, the factors behind missing R&D expenditures are less obvious to understand.

We estimated a pooled regression model on the whole data. Our choice of variable is crucial but limited by the small number of firms in our sample and the overrepresented amount of zeros for R&D for most of them. We selected the following variables: firm size, intangible assets (intangible assets include capitalised R&D) divided by size, profitability, indebtedness divided by size, deregulation (see the 'DATA' section for their definition). As in Sanyal and Cohen (2008) we find that the size of electric utilities matters in the decision to report R&D, or bigger firms are more likely to engage in R&D than smaller firms. Apart from profitability and capitalisation, all variables are significant at the 5% level. The estimate of the coefficient multiplying debts has a negative sign which suggests that electric utilities may decide or not to report R&D to have some control over their indebtedness.

The next step consists in re-estimating the equation for R&D in level and correcting for sample selection. We estimate that model after removing the variables that were non significant in 'Model 3'. The results are reported in the second column of Table 3 ('Model 4').

Further results

We interpret the results from 'Model 5' which by considering the entire set of observations seem to produce more precise results. The coefficient on the firm size variable is largely in favour of the Schumpeterian hypothesis. The Student statistics associated with $H_0^1 : \beta_2 \leq 1$ is equal to 5.937 that is largely above the critical value. We thus reject the hypothesis of proportionality and of an advantage of small firms in R&D in favour of the Schumpeterian hypothesis. We also estimated the tobit model with sales net of R&D rather than assets as the size variable to avoid the critic point out in Hall et al. (2007) that there is a simple accounting correlation between size and R&D. This correlation should imply a one for one relationship between R&D and size. With sales net of R&D we still find a significantly positive coefficient that is not statistically different to 1 at the 5% level (0.917). But since its value is lower to unity we must reject a higher than proportional relationship between R&D and net sales whereas we accept with assets as the size variable. The bottom line is that proportionality characterises electric utilities, which lends credence to Cohen and Klepper's CSA hypothesis for electric utilities.

The financial variables (debt and dividends) are negatively related to R&D. This result for the former variable supports the behaviour of electric utilities during the past ten years by which they spent considerable funds to make domestic and cross-boarder M&A operations. An increase of 100,000 euros in dividends is associated with a 4.1 percentage points decrease in R&D. Thought the M&A variable itself was not significant throughout the regressions, indebtedness was. The result for dividends in more politically sensible as it would suggest that research is an alternative use of funds to paying dividends, or the higher the money paid to investors, notably private investors, the lower is the amount spend in R&D. The non-significance of the cash variable in all our regressions would suggest that electric utilities are not financially constrained. As we mentioned earlier, cash flow sensitivity of R&D investment needs not identify liquidity constraints but rather is indicative of high demand and expectations of future profits. We controlled for that by considering a measure of domestic wealth at the country level, namely GDP. Perhaps that a more precise measure of the demand addressed to the electric utilities would lead to a different result, which is left for a future version of the present paper.

The coefficient on the effect of deregulation is still negative and significant. As the variable is a dummy and R&D is measured in logarithm, we deduce the percentage impact of the deregulation variable on R&D from the formula given for example in Sanyal and Cohen (2008, footnote 44). We find a negative impact of 135% which is considerable but fully consistent with the figures of decrease in R&D hence R&D intensity for some firms.

The variable of fuel mix that is the ratio of thermal to renewable electricity generation also has the expected sign: firms in countries with a relatively higher share of clean energy needs less to spend in R&D. To put it differently, our result suggests that firms that produce electricity from energy resources that are detrimental to the environment are also those that spend more in R&D, everything else being equal.

CONCLUSION

The present paper aims to provide a better understanding of the effect of reforms on R&D by electric utilities. Following previous works done for U.S. electric utilities, we expect that it will contribute to the formulation of more effective energy R&D policies, a claim made for by Jamasb and Pollitt very recently. Our results have some implication regarding the consequence on innovation of merger policies. The most obvious is that by preventing consolidation of the larger firms, competition commissions may impede increases in total industry R&D efforts.

While special attention was given to firm size, the present paper provided insights into a larger number of factors behind innovation input. Overall, these results also suggest that the management of activities associated with discovering new knowledge and applying it to new products is likely to be different in the electricity sector to other industries. The main reason is that electric utilities are subject to specific regulations and obligations. As we have shown, these peculiarities are such that electric utilities were and still seem not subject to financial constraint. But, it turns out that the entry of new investors, following the privatisation of electric utilities, are creating some competition for funds, notably at the expense of R&D.

Further analyses are left for future researches. First of all, it would be interesting to increase the number of firms so as to be able to estimate less misspecified models and consider more variables, notably, to have a clearer control on the influence of the decision by firms not to report R&D. Regarding other measures of innovation, a complementary research would be to see whether large electric utilities generate more or less innovations per euro of R&D. As this research contributes to the more general question of what is the profile of electric utilities that are more likely to spend in research and development, and since these firms are necessarily those more likely to 'survive' in an environment under competitive pressures, an deep analysis of the determinants of M&A operations would be very valuable too.

As suggested in Hall (2002), there can also be an important role for policy based on the existence of significant spillovers and externalities, rather than on the financing-gap argument, in particular for large established firms. The electricity industry is a case in point. This is perhaps more important an argument than those based on the existence of financial constraints which are much more crucial consideration for small and start-up firms in R&D-intensive industries.

NOTES

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2. This issue is becoming of practical interest to competition commissioners who should base their decision to cancel or not a merger on the basis of the consequences a more concentrated liberalised market would have on the propensity of the candidates to the merger to innovate.
3. To fully understand this argument, it is worth noticing wholesale markets deregulation is always followed by a progressive opening up of retail markets to competition.
4. Margolis and Kammen (1999) yet noticed the little work done on return on investment s in R&D in the energy sector. A possible reason of the lack of such analyses could be that the capital structure of electric utilities still remains, to a significant extent, in the hands of regulators and administration, although this dependence varies across countries and over time, depending on the degree of market liberalisation, firms' privatisation and divesture. This introduces some heterogeneity which can't simply be controlled for by including firm or industry effects. As a consequence, the behaviour of electric utilities and utilities in general, is analysed in papers specific to this category of firms.
5. A private discussion with an employee involved in R&D activities at Electricité de France (the firm is floated since November 2005) revealed that R&D expenditures aimed to increase energy saving by consumers is more strategic than ever before.
6. Obviously, some innovation is more specific to a type of power plant. As an example, operating costs in nuclear energy are directly related to incidents, the occurrence of which can be reduced from organisational (process) innovations which can give to the firm a competitive advantage (see Roux-Dufort and Metais, 1999 who address this issue in the case of the nuclear power producer, Electricité de France; the firm changed its way of managing nuclear risks by introducing in 1982 an organisational innovation known as the 'Human Factor' policy).
7. Baumol (2002, p. 154) defines product innovation as one innovation that shifts the demand curve for the affected final product to the right, while a process innovation shifts the pertinent cost curves downward. If successful, process innovation can expand output and reduce product price. If, at the converse, marginal cost rises, this is accepted in returns for a large cut in fixed costs. The distinction between product and process innovation is not clear in the field of environmental researches, however '… because significant improvements of environmental conditions may be attained by both types of innovations.' (Horbach, 2008, p. 169).
8. This is a consequence of the second condition of the CSA, that at any given moment, electric utilities are not expected to grow rapidly due to innovation. Furthermore, R&D expenditures are usually budgeted several months before they are spent (Cohen and Klepper, 1996, pp. 926, 937)
9. Unlike Wilder and Sansell (1974) we do not have the ratio of electric to total operating revenue for all years of our sample of observation.
10. See Jamasb and Pollitt (2008, 2009), Johnstone et al. (2008), Sanyal and Cohen (2008) and Sanyal (2007) for more details on innovation by electric utilities.
11 A more documented definition can be found in Datastream. Note that it excludes government sponsored research, contributions by government, customers, partnerships or other corporations to the company's research and development expense.
12. In 2008 it spent about one fourth of its R&D budget to environmental projects (EdF, 2008, p. 185).
13. Defeuilley and Furtado (2000) report a change from £201 millions in 1998 to £40–50 millions in the 1990s of researches aimed at nuclear energy.
14. There are studies with less gross measures of R&D. As an example Sanyal (2007) uses environmental R&D whereas Sanyal and Cohen (2008) use total R&D expenditures that include all internal and external R&D expenditures by the utility. Within internal there is expenditure of generation, transmission, distribution and environmental projects. The external R&D is contributions to the research institutes. I thank Paoma Sanyal for pointing out this distinction to me.
15. A pooled regression of total assets on sales and a constant leads to a R^2 equal to 0.98; the coefficient which multiplies the constant is not significantly different from zero at the 1%

level of significance whereas the coefficient multiplying sales equals 1.71 with a standard error of 0.041.

16. Relatively high-cost generating facilities, and more generally costs that are not expected to be recovered in a competitive wholesale power market (Blacconière et al., 2000).
17 Upstream firms traditionally used to undertake research projects in collaboration with electric utilities as evidenced e.g. through the EdF/Areva and E.ON/Alstom/Siemens established partnerships. In the case of electricity industrial policies prompt cooperative research which allows electric utilities and equipment builders to share the cost of some R&D project, e.g. the joint EDF-Areva project for construction of a pressurised water reactor, the EPR.
18. In their paper, O_{ct} is constant and as such it enters the intercept. Regarding productivity it is calculated once for all in their paper as they transformed their panel data to a cross-section by averaging over their annual observations. This specification allows marginal returns to R&D to vary across firms according to the value of β provided we assume that that parameter varies across firms (Cohen and Klepper, 1996 allow that parameter to vary across industries). We keep that parameter constant and consider O and N as alternative factors likely to influence the R&D-size relationship.
19. This would be possible by analysing corporate web sites which are available at most for the last two to five years for most firms.
20. In a private discussion the author gave as justification that since in her 2007's paper R&D is just environmental, the selection equation there was whether the firm first decides whether to conduct environmental R&D or not, thus suggesting that the larger selection decision would be at the aggregated R&D level as supported in Sanyal and Cohen (2008).

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