Deregulation and R&D in Network Industries: The Case of the Electricity Industry

Tooraj Jamasb and Michael Pollitt

August 2005

CWPE 0533 *and* EPRG 02

These working papers present preliminary research findings, and you are advised to cite with caution unless you first contact the author regarding possible amendments.

DEREGULATION AND R&D IN NETWORK INDUSTRIES: THE CASE OF THE ELECTRICITY INDUSTRY*

*Tooraj Jamasb***

Faculty of Economics, University of Cambridge

Michael Pollitt

Judge Institute of Management, University of Cambridge

18 June 2005

* The authors acknowledge the financial support of the EPSRC's SuperGen project. They are grateful to David Newbery and Beth Morgan for extensive comments. All remaining errors remain the responsibility of the authors.

** Corresponding author. Faculty of Economics, University of Cambridge, Sidgwick Avenue, Austin Robinson Building, Cambridge CB3 9DE, United Kingdom.
Phone: +44-(0)1223-335271, Fax: +44-1223-335299, Email: tooraj.jamasb@econ.cam.ac.uk

Abstract

Implementation of electricity reform has coincided with a significant decline in energy R&D activities. Technical progress is crucial for tackling many energy and environmental issues as well as for long-term efficiency improvement in the sector. This paper reviews the industrial organisation literature on innovation to explore the causes of the decline in energy R&D spending and shows that it was predicted by the pre-reform literature. More recent evidence endorses this conclusion. At the same time, R&D productivity and innovative output appears to have improved in both electric utilities and equipment suppliers, in line with general improvements in the operating efficiency of the sector. Despite this, a lasting decline in basic R&D and innovation input into basic research may negatively affect development of radical technological innovation in the long run. There is a need for reorientation of energy technology policies and spending toward more basic research, engaging more firms in R&D, encouraging collaborative research, and exploring public private partnerships.

JEL Classification: L94, O38

Keywords: innovation, R&D expenditure, electricity reform, regulation, ownership

1. Introduction

The 1990s witnessed the emergence of electricity sector reform in many countries across the world. The main objective has been to improve operational and investment efficiency through restructuring, competition, regulatory reform, and privatisation. Reform has taken place against the backdrop of a broader paradigm shift from state ownership and centralised management of infrastructure industries, to one that favours decentralised structures, competition, independent regulatory oversight, and private ownership (OECD, 2000). In addition, technological progress facilitated the implementation of electricity reforms by reducing economies of scale and improving the efficiency of new generation plants, factors which lowered barriers to entry by reducing the up-front capital costs, operating costs, construction periods, and environmental impacts (Hirsh, 2000).

It is important to analyse the effects of market-oriented reforms on research and development (R&D) efforts, and on innovation. This is because the primary aim of restructuring is to improve short to medium term efficiency and this may be offset over the longer term by lower rates of technical progress. However, these effects have received limited attention and have had little influence on policy. It had been assumed that private actors, competitive forces, and profit incentives would encourage the necessary levels of R&D efforts with greater precision and efficiency (see e.g. IEA, 1999; USHR, 1998).

However, there is evidence that implementation of electricity reform has coincided with a significant decline in R&D activities. Figure 1 also shows some tendency toward reduction in governments energy R&D budgets around the time of reform in major IEA countries It appears that spending in countries with the most extensive reforms (e.g. the UK and Spain) show a downward trend than in countries with least extensive reforms (e.g. Japan and France). Although total government spending in IEA countries has remained relatively stable since 1990s, these are substantially lower than those of mid-1970s and mid-1980s period (IEA, 2004b). Although, there are signs of a modest recovery in government energy R&D spending in recent years, this does not weaken the need for debating the role of government spending and R&D policy in promoting energy technology innovation.

There is less data on energy R&D spending in the private sector as, since liberalisation, such information has become commercially sensitive. However, indications suggest that also here there has been a reduction in spending on R&D by electric utilities and, to some extent, by the major suppliers of electric equipment (see Sanyal and Cohen, 2004;

Eurelectric, 2003; Defeuilley and Furtado, 2000; Margolis and Kammen, 1999; Bell and Schneider, 1999; Dooley, 1997). Figures 2 and 3 show that these has been a marked decline in R&D spending by private electric utilities in the US and Japan in the post-liberalisation years.

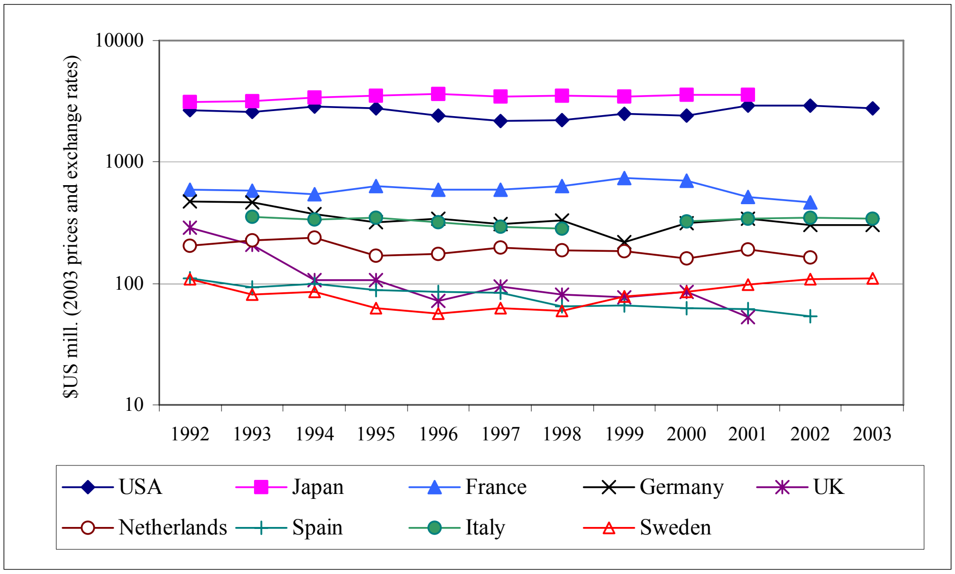

Figure 1: Government energy R&D spending in IEA countries
Source: IEA (2004a)

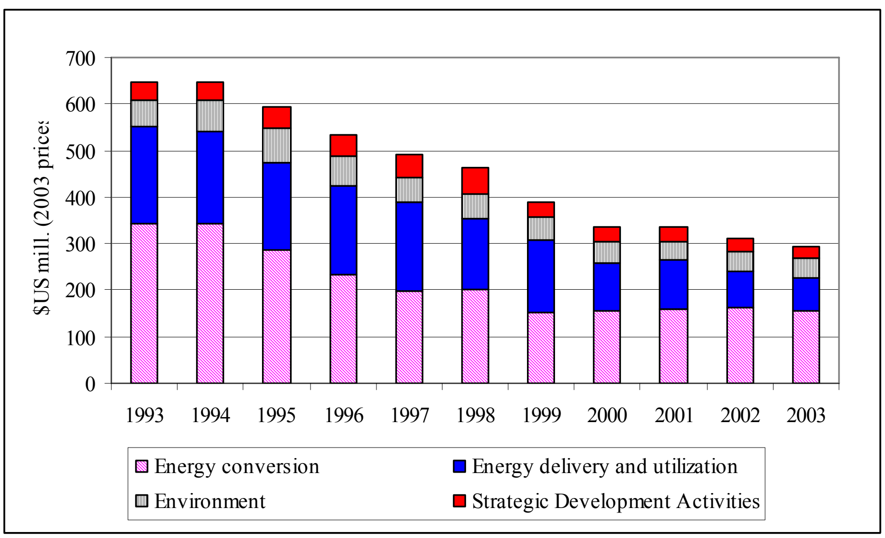

Figure 2: Collaborative research through EPRI
Source: EPRI annual reports

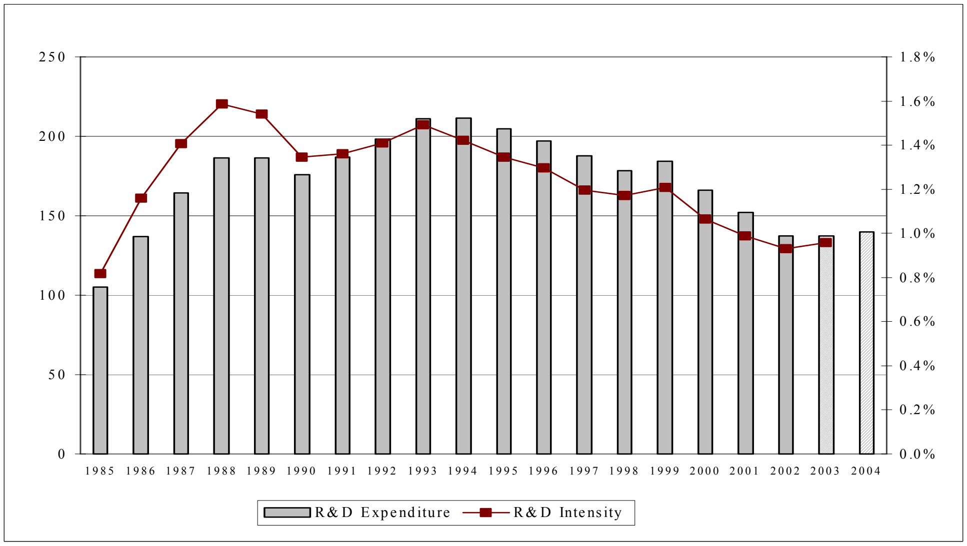

Figure 3: Private electricity R&D in Japan (billion yens - estimated spending for 2003 and budgeted amounts for 2004).
Source: In Hattori (2005) based on FEPCO/CEPC (2004).

R&D expenditure is just one of the costs incurred by a liberalised industry. Liberalisation leads to cost reductions in operating expenditure and capital expenditure as a result of pressure on utilities to improve financial performance. This should reflect genuine efficiency improvements. As such lower private R&D expenditure, in the context of lower overall expenditure, may be part of general efficiency improvements. The reason for our focus on this element of costs is that private R&D expenditure has fallen much faster than overall expenditure in the electricity supply industry as indicated by the declines in R&D intensity above. This may indicate the emergence of a significant market failure with respect to R&D expenditure. We do not expect to be able to definitively conclude on the extent to which R&D expenditure is currently suboptimally low (or whether it was suboptimally high prior to reform), but to highlight low R&D expenditure as a relevant policy issue.

Kamien and Schwartz (1975) show that, on the whole, there is a positive relationship between innovative input, such as research and development (R&D) expenditure, and innovation outputs. Perelman (1995) finds that total factor productivity (TFP) in the Organisation for Economic and Cooperation and Development (OECD) manufacturing sectors is correlated with R&D intensity (the ratio of R&D spending to gross domestic product (GDP). In the electricity sector, technological progress is a key factor for long-term efficiency improvement and for aligning the economic and environmental objectives in a sustainable development framework.

Importance of energy R&D in the context of electricity reform is highlighted by the fact that about 98 percent of the R&D expenditures by countries member in International Energy Agency (IEA) R&D takes place in 10 major economies (Margolis and Kammen, 1999). The major energy R&D spending countries, whether under public or private ownership, have embarked on some form of electricity reform and, as a result, the economic and environmental benefits of technological progress must increasingly be achieved in market-oriented environments. However, reform implementation has proved to be considerably more complicated than anticipated, design and policy issues remain to be solved, and uncertainty has increased. This is at a time when technical progress in flexible generation technologies, increased use of renewable sources, and distributed generation, can lead to new opportunities for reform.

The direction of the causal effect between technological progress and reform may have been reversed, as there has been a marked reduction in the level of R&D activities. The literature is generally positive about the performance effects of liberalisation, although some authors raised concerns regarding the long-term effects of a decline in energy R&D (see GAO, 1996; Dooley, 1997; Bell and Seden, 1998; Bell and Schneider, 1999). Moreover, there is limited sign of coherent energy R&D and technology policies after deregulation. This vacuum may be partly explained by the constant short term challenges posed by reform which make consideration of long term effects less of a priority. A better understanding of the factors and mechanisms affecting energy R&D in a deregulated environment will be a significant contribution to formulating appropriate energy R&D policies.

That said, there is a rich body of theoretical and empirical literature on R&D and technical change within the framework of an industrial organisation paradigm. Much of this literature was written before the recent reform period (which we date from around 1990). Although general structural characteristics of most industries are stable over time, the introduction of sector reforms will affect some of these characteristics in a fundamental way. Therefore, examining the effect of (reform-induced) structural and related changes in the electricity sector is a rare opportunity to revisit and assess their impact on R&D conduct and industry performance. It is the thought that this literature might have predicted the sharp decline in R&D expenditure following liberalisation which is the major motivation for this paper.

In what follows we examine the effect of electricity reform on energy R&D activities within the framework of the industrial organisation paradigm. Section 2 presents: (i) evidence on post-reform energy R&D efforts with an emphasis on the ten leading countries, (ii) relevant aspects of reform and sector policies, and (iii) outlines a model of electricity reform and R&D. Section 3 is a review of the relevant R&D literature and the extent to which it apparently explains the relationship between electricity reform and R&D. Tables 3, 4 and 5 summarise the main findings of this section. Section 4 contains a conclusion and policy implications. Appendices expand the review summaries in Section 3.

2. Energy R&D and Electricity Reform

2.1 Elements of Electricity Sector Reform

The accumulated experience of electricity liberalisation since the 1990s has led to the identification of a set of generic reform steps for a well functioning market-oriented sector. Liberalisation generally requires implementation of one or more of the following steps: sectoral restructuring, introduction of competitive markets for wholesale generation and retail supply, regulation of transmission and distribution networks, establishment of an independent regulator, and privatisation of assets (Newbery, 2002; Jamasb, 2002; Joskow, 1998). Table 1 outlines the main measures of a generic liberalisation model for transforming a vertically integrated publicly owned monopoly into a privately owned competitive sector. In practice, the actual measures need to be adapted to take the specific characteristics of a given sector into account e.g. structure, system size, ownership, and resource endowment, as well as the desired features of the liberalisation model to be implemented.

Table 1: Main steps in electricity reform

Restructuring	- Vertical unbundling of generation, transmission, distribution, and supply activities
	- Horizontal splitting of generation and supply activities
Competition and Markets	- Wholesale market and retail competition
	- Allowing new entry into generation and supply
Regulation	- Establishing an independent regulator
	- Provision of third-party network access
	- Incentive regulation of transmission and distribution networks
Ownership	- Allowing new private actors
	- Privatising the existing publicly owned businesses

The main perceived effect of privatisation comes through incentives to pursue profit through cost saving and efficiency. Often, the structural effect of the change from public to private ownership is a shift from a single to a plural ownership mode that facilitates direct competition in the wholesale generation and retail supply activities, and incentive regulation of transmission and distribution networks.

Structural changes generally involve unbundling the various functions of vertically integrated entities with the aim of separating the potentially competitive functions from natural monopoly networks. This is generally achieved by functional or legal separation. Restructuring can also involve horizontal splitting or merging of companies within an activity. Unbundling, therefore, affects both the size and concentration of firms in the market. Establishment of wholesale and retail markets is central to liberalisation, and transforms the organisation of the sector and the operating environment of companies. In addition, the establishment of an independent regulatory authority changes sectoral governance and rules of conduct for the firms in the market. The main regulatory functions are to ensure well functioning competitive generation and supply markets and non-discriminatory access to transmission and distribution networks. In many cases, the primary objective of the regulator is to protect the interests of the consumers while ensuring that investments can be financed.

2.2 Background to liberalisation

The main objective of electricity reform is to improve the efficiency of the sector. Empirical evidence suggests that, on balance, reforms have resulted in improved efficiency and cost savings (Domah and Pollitt, 2001; Jamasb et al., 2005; Newbery and Pollitt, 1997; Markiewicz et al, 2004). There are differing theoretical perspectives as to how market-based reforms and private ownership might lead to greater efficiency; Pollitt (2002) classifies the relevant theories as: (i) property rights theories, (ii) bureaucracy theories, (iii) influence theories, (iv) economic regulation theories, and (v) commitment theories. On balance, theory predicts that reforms will lead to higher efficiency.

Hart et. al. (1997) suggest that public ownership is superior to private ownership only in a narrow range of circumstances. Megginson and Netter (2001), in their assessment of empirical studies of privatisation world-wide, conclude that there is strong evidence that privatisation improves operating performance, however, ineffective regulation and a lack of government commitment may negate the expected benefits of reform. Galal et al. (1994) stress that arguments explored by property rights, public choice, and bureaucracy theories are not applicable to all market structures. De Fraja (1993) shows that, within the framework of principal-agent theory, public enterprise performance evaluation and optimal contracts can be more efficient than the profit incentive of private firms. Pint (1991) suggests that both public enterprises and regulated private firms are less efficient than the second-best efficient solution in natural monopoly; the former by excessive use of labour and the latter by excessive use of capital.

Schneider and Jäger (2003) identify three theoretical approaches that attempt to explain the recent trend toward the withdrawal of the state from infrastructure industries. (i) Dynamic theories of diffusion and contagion emphasise the co-evolution and intertwining of national policy making through (inter-sectoral and general economic) embededness into an international environment. (ii) Structuralist and functionalist theories of economical and technological determination stress the inevitability of the withdrawal of the state as a consequence of structural changes from global economic integration and technological evolution. (iii) Actor-centred and institutionalist theories of political scope of action reject the notion of the inevitable convergence of policies leading to an identical withdrawal path across countries and emphasise feasibility of multiple and country-specific paths and models.

The emergence of the liberalisation paradigm of infrastructure industries may be explained in terms of pull and push theories and the arguments discussed in the above. At the same time, the positive macroeconomic effects of liberalisation may yet need to be established. Historically, as Chang (2003) points out, in all developed economies interventionist policies played an active role, and there is no theoretical reason for a more liberalised economy achieving higher allocative efficiency, or for higher allocative efficiency leading to higher economic growth. Indeed Oulton (1995) suggests that the UK economy was characterised by low growth in the 1980s and early 1990s because the positive effects of liberalisation were offset by poor macro-economic management.

2.3 Why reform might impact energy R&D

This section examines the possible effects of electricity liberalisation on energy R&D within the industrial organisation perspective using the *structure--conduct-performance* (SCP) paradigm of industrial organisation. We focus on the most commonly implemented reform steps that are likely to have a considerable impact on R&D activities.

The crucial task in implementing electricity reform is how to provide the necessary conditions for efficient operation and investments in a sector that is characterised by: (i) large sunk costs, (ii) a mixture of competitive and natural monopoly activities, (iii) organised markets with instantaneous physical balance of supply and demand, and (iv) delivery of a non-storable good.[1]

Theory suggests that competition and profit incentives result in internal (product) and external (market) efficiency and that the gains from these are passed to customers and the economy in the form of lower costs and prices. In principle, R&D investments should play a central role in product and process innovation and achieving competitive advantage in the market. However, R&D often has some characteristics of public goods that limit the scope of private involvement in these. The potential for the occurrence of spill-overs and limits to appropriation of results reduce potential returns from R&D to private investors. In addition, uncertainty about the outcome of R&D investments tend to have a negative effect of R&D spending. These factors lead to lower than optimum R&D investments from a social point of view. Further, the existence of network externalities implies that the system-wide costs and benefits do not always coincide.

In the light of theory and evidence it is plausible that electricity liberalisation can achieve (short-term) operating efficiency through the spread of best practice. The logical extension of the above argument is that liberalisation will also lead to improved (mid-term) investment efficiency and adoption of best available technologies. A further extension of this logic suggests that firms will also have the incentive to engage in development of new technologies to gain competitive advantage in the asset base and operation through R&D. Indeed, the greatest potential for efficiency improvement in the sector lies in long-term technical progress that expands the boundaries of possibilities and achieves a positive shift in the efficient frontier. However, it is less clear whether, due to the particular characteristics of the sector, such a sequence of logical arguments and predictions will, in reality, hold and deregulation will result in higher long-term technical progress than the pre-reform models. This may be because de-regulation systemically lowers the willingness of the sector to take technological risks and results in the favouring of the use of established technologies with low up front capital costs.

The main focus of the early economic literature on science and technology was on the impact and measurement of technological change on output and growth. A common characteristic of these studies was their treatment of technical change as a factor

[1] The latter two characteristics are because of properties of electricity which are such that it can only be stored at relatively high cost and that in an electricity network supply must equal demand at every node at all times or else unacceptable variations in voltage occur.

exogenous to the economic system. This approach has had clear limitations in a policy analysis and advice perspective. Since the 1960s, the focus has shifted to the study of the effect of economic factors on technical change (Thirtle and Ruttan, 1987). This newer approach views technical change as a factor that is endogenous to the economy and focuses on determinants of technical change and the role of policy in achieving it. This view stems from recognition of the importance of technical change for economic growth and the desire to influence its course and rate of progress. In other words, the new framework assumes that technical change can be induced. The notion of induced technical change is relevant and appealing for addressing energy and environmental issues where the economic, political, and social stakes are high (Grubb et al., 2002).

The different stages and processes in technical change have been described in various ways. The most established of these is the paradigm generally referred to as the Schumpeterian trilogy based on the concepts of invention, innovation, and diffusion (Schumpeter, 1934; 1942). In this framework, invention is described as the generation of new knowledge and ideas. In the innovation stage, inventions are transformed into new products. Finally, the diffusion stage is the widespread adoption of the new products. An alternative paradigm to describe technical change distinguishes between science and technology. Here, science broadly refers to the earlier (and non-commercial) phases of the trilogy, while technology is associated with profit seeking activities and latter stages of the process. There is a degree of correspondence between the process of technical change and main stages of R&D comprising basic research, applied research, and development activities. Basic research is broadly related to the invention stage while applied research and development activities are related to innovation and diffusion phases. The relationship between the stages in the technical progress is not necessarily linear. Rather, the process of technical change encompasses various feedback loops between these components (Stoneman, 1995: 2-5). The inter-relations and feedback in the innovation process are, however, not well understood and the search for a coherent theory of the determinants of technological innovation remains elusive.[2]

[2] One approach to the measurement of technical change that has recently gained renewed attention is to quantify the effect of the chain of activities and interrelations leading up to technical progress and is based on the measurement of the learning effect using technology learning curves. The concept of the learning effect as a distinct source of technical change is generally termed as "learning-by doing" and was presented in Wright (1936) and Arrow (1963). The learning effect is generally derived from learning curves where technical change is expressed by the reduction in unit cost or price as a function of accumulated capacity or output. More recently, the notion of learning effect has been extended to include "learning-by-researching" where research is assumed to result in learning by enhancing the knowledge base, which in turn promotes technical progress. In some empirical analysis of technical change, the learning effect of research is accounted for in "two-factor learning curves" that use cumulative R&D spending or number of patents as a proxy for stock of knowledge (Kouvariatakis, 2000).

Recognition of induced technical progress implies that policy can play an important role in directing the process of change. A typology of policies, consistent with the framework outlined in the above divides these into supply push and demand pull policies. The aim of supply push policies is to promote the generation of knowledge and development of new technologies. In turn, market or demand pull policies are devised to promote technical change by creating demand and developing markets for new technologies and products.

The specific steps aimed at implementing market-oriented electricity reforms, can have a profound impact on the activities and processes that lead to technical progress in the sector. In the light of the decline in R&D efforts in the aftermath of reforms, the market failure view provides a plausible framework for examining the effect of reform on R&D and innovation in the sector. R&D activities are subject to three main types of market failure namely indivisibility, uncertainty, and externalities (Ferguson and Ferguson, 1994). Therefore, it is possible that market failure associated with reforms play a role in the recent decline in R&D activities. Table 2 outlines aspects of the effect of the key reform steps on the structure, organisation, and drivers of the sector's innovative input and outputs. The table also shows the parallels with the components of the structure-conduct-performance paradigm which form the basis of the selection and evaluation of the empirical and conceptual evidence reviewed in this paper.

Table 2: A S-C-P model of electricity reform and innovative activities

STRUCTURE	CONDUCT	PERFORMANCE
Reform Steps	**R&D Input**	**R&D Output**
● Restructuring (Section 3.1) - *Firm size* - *Degree of Vertical integration* ● Ownership (Section 3.2) - *Ownership type* - *Privatisation* - *Mergers & acquisitions* ● Regulation (Section 3.3) - *Rate of return regulation* - *Incentive regulation* - *State vs. local regulation*	● R&D spending ● R&D intensity ● R&D organisation	● Patenting activity ● Technology adoption ● Technical change

3. Empirical Studies of Innovation in Industrial Organisation

There is an extensive empirical industrial organisation literature addressing various aspects of innovation. However, only a small subset of this literature covers the issue of innovation in electricity sector. An even smaller number of studies address innovation within the context of market-oriented reforms in infrastructure industries. Therefore, in order to enhance our understanding of the effect of electricity reform on innovation, we cast our net wider and review the evidence from other relevant studies.

Nearly all the industrial organisation literature on innovation examines the causal relations for a given market/regulatory design or compares innovation across market/regulatory designs - for example, the effect of firm size or regulation on the innovative efforts of firms. However, it is uncommon that important features of the entities being studied are subject to change.

3.1 Restructuring

In many instances, a full scale physical restructuring requires breaking up vertically integrated systems through vertical separation i.e. unbundling of interconnected activities and horizontal splitting of the entities that are deemed too large. Unbundling separates the potentially competitive activities from network activities as natural monopolies while horizontal splitting aims to curb market power and dominance of large firms. Moreover, an organised wholesale market for generation needs to be established and barriers to new entry need to be lowered.

Vertical unbundling and horizontal splitting change firm size and market concentration. The effects of firm size and market concentration on firms' innovative activities are arguably the most widely studied aspects of the relation between market structure and innovation in the industrial organisation literature. However, as mentioned, this has almost entirely been done by comparing differences across firms and industries rather than in the context of the changing circumstances of the same firms and industries resulting from, for example, a reform.[3]

---

[3] A notable exception is the discussion of impacts of forced vertical and horizontal separation in the US petroleum industry on energy R&D in the 1970s (see Teece, 1997).

Firm size and market concentration

The literature on the effect of firm size and market concentration on innovative activity is extensive and we do not attempt to settle these questions or to survey this literature here. Scherer and Ross (1990), Cohen and Levin (1988), Williamson (1983), and Kamien and Schwartz (1975) present comprehensive reviews of the state of debate and evidence on these issues. On balance, surveys of the Schumpeterian hypotheses and their variations suggest that the theory and empirical evidence are not conclusive. Overall, the important and relevant lessons that emerge from this literature suggest that both competition and monopoly can, up to a point, encourage innovative activity. Therefore, in order to achieve long run technical progress, a balance must be struck with regards to the thresholds in the constructive forces of these factors. This balance between competition and monopoly, however, can vary with firm and industry specific characteristics.

The evidence emerging from the literature testing the Schumpeterian hypotheses using 'within industry' samples are more conclusive and supportive. Cohen and Klepper (1996) summarise these findings as: "(1) the likelihood of performing R&D rises with firm size; (2) R&D and firm size are closely and positively related within industries; (3) R&D spending rises proportionally with firm size in most industries; (4) the number of patents or innovations generated per dollar of R&D declines with firm size." The study analyses data from 75 US industries between 1975-1977 using an R&D cost spreading model (i.e. large firms distribute the R&D costs over a greater number of units of output). The results support the findings from previous studies. In addition, the study shows that although R&D productivity may decline with size, large firms benefit from R&D cost spreading.

The main causes of the post-reform decline in energy R&D can be explained in terms of the effect of implementation of reform steps such as restructuring on the specific characteristics of the electricity industry. We now turn to the limited number of the studies of the subject in the electricity sector. This literature is almost entirely on the US electricity sector and prior to the reforms in some states. This can be explained by the existence of a large number of privately owned regulated utilities in the US, as opposed to the state-owned and vertically integrated models that were dominant in most of the world, thus offering the opportunity to test various regulatory economics or industrial organisation hypotheses.

Wilder and Stansell (1974) examine the determinants of R&D spending including firm size in US electric utilities. The study uses data from over 200 utilities involved in the electricity sector between 1968 and 1970. The size and involvement of utilities in the electricity sector is measured by operating revenues and their share of operating revenues from electricity respectively. The results show that R&D outlays of utilities are positively correlated with their size. The coefficients are significantly greater than zero and one indicates that elasticity of R&D response to firm size is larger than one. Also, share of electricity in total operating revenues is positive and significantly different from zero (its difference from one is, however, insignificant) indicating R&D spending is more associated with electricity than other utility operations. Delaney and Honeycutt (1976) replicate the analysis in Wilder and Stansell after adjusting the sample for firms that are subsidiaries or part of joint ventures and holding companies. The adjustment reduced the sample size to 135 utilities and the analysis was performed for 1970 and 1972. Analysis of the adjusted sample confirmed the results by Wilder and Stansell for firm size and share of revenues from electricity.

Also, two other studies of US electric utilities, Flynn and Mayo (1988) and Sanyal and Cohen (2004), find that firm size (measured in physical output and operating revenue respectively) have a positive and significant effect on their R&D spending. The latter study also finds that post-deregulation R&D elasticity of size is lower (0.83) than that of pre-deregulation period (0.96). Furthermore, Cohen and Sanyal (2004) find that internal and external R&D of US electric utilities increase with firm size though the effect on internal R&D is rather stronger.

The elasticity of R&D spending with respect to size for electric utilities in the above studies is indicative of, at least, part of the observed reductions in R&D spending in the aftermath of reforms in the US and elsewhere. The estimated elasticities of R&D in these studies vary significantly: Wilder and Stansell (1.29-1.40), Delaney and Honeycutt (1.45-1.61), Flynn and Mayo (1.0), Sanyal and Cohen (0.84-0.96), and Cohen and Sanyal (0.87 and 1.8 for internal and external R&D respectively). Since vertical unbundling and horizontal splitting of utilities can reduce the size of large utilities significantly, these results imply possible large reductions in utility R&D spending as a result of restructuring.

Benefits of R&D are achieved only when firms adopt the innovation output of R&D. Therefore, factors that affect the propensity of adopting new technology by firms are as important as R&D and innovation. Rose and Joskow (1990) present an econometric analysis of adoption of new generation technologies in the US electric utilities. The paper examines the effect of firm size, fuel cost, and ownership on adoption of two coal-fired steam-electric technologies. We return to these effects of ownership in next section. The study uses statistical models of hazard rate to estimate adoption probability of subcritical 2400 psi and supercritical above 3206 psi generation technologies between 1950 and 1980. The results show that large utilities are significantly more likely to adopt new technologies than small firms although the relationship is non-linear and declining. A 10 percent increase in firm size increases the hazard rate by 7-8 percent. The paper also finds that larger firms have greater technological opportunity for adopting new technologies and failure to control for this factor leads to overestimation of the effect of firm size on adoption of new technologies.

Vertical integration

The progress in electricity generation technologies achieved during the 1950s and 1960s mainly favoured larger units. It is, therefore, conceivable that large utilities were better positioned to benefit from the scale factor that new technologies offered (see Hughes, 1971; Hirsch, 1999). Moreover, Hughes (1971) argues that, in the US electricity sector, economies of co-ordination would be best utilised in a structure that consisted of about twenty large vertically integrated utilities.

An important argument in support of vertically integrated structures in the electricity sector is based on the perceived benefits of the economies of vertical co-ordination. Kaserman and Mayo (1991) identify market uncertainties, small numbers bargaining, large quasi-rents, and vertical externalities (e.g. technological externalities and moral hazard) as characteristics of intermediate product markets in vertically separated and competitive electricity sectors. Kaserman and Mayo (1991) then use data from 74 US electric utilities to find that the firms' total operating expenditures are significantly negatively correlated with the degree of vertical integration. They also suggest that the economies of vertical integration are likely to be larger than benefits of operating in a competitive market. Other studies such as Nemoto and Goto (2004), Hayashi et al. (1997), Gilsdorf (1995, 1994), and Lee (1995), have found evidence of economies of vertical integration in electricity industry. In the UK significant re-integration of unbundled utilities has incurred following extensive dis-integration prior to the start of recent reforms (see Newbery, 2005).

Kaserman and Mayo (1991) also argue that co-ordination among utilities in the form of being part of a holding company, participation in joint ventures, and power pooling may offer some of the benefits of vertically integrated structures. The results do not indicate significant cost savings for participation in holding companies and are thus in agreement with findings of Huettner and Landon (1978) and Christensen and Greene (1978). The study does not explicitly account for power pooling among the firms. At the same time, there is no evidence of significant cost saving from power pooling arguing that transaction costs and lack of regulatory incentives have resulted in loose arrangements that have not produced significant cost savings (Christensen and Greene, 1978; Cramer and Tschirhart, 1983; Gegax and Tschirhart, 1984).

Joskow (2002) discusses electricity reform issues in the light of some characteristics of the sector i.e. limited adaptability of existing assets, and the apparent economies of co-ordination in vertical integration structures. The paper argues that while reforms have achieved improvements in operating efficiency, their long-term benefits from resource allocation are yet to be determined. Joskow stresses the importance of adopting a transaction costs approach to design and evaluation of electricity reforms and that the perceived benefits of reforms need to offset the increased transaction costs resulting from unbundling.

At a general level, if vertical integration offers benefits in terms of economies of co-ordination for the overall operation of the firms, such benefits are also likely to be present in innovative activities. In an analysis of the determinants of vertical integration in US manufacturing industries, Levy (1985) finds evidence that research intensity (interpreted as transaction specificity) has a positive and significant effect on vertical integration. Armour and Teece (1980) examine research expenditures in the one hundred largest US petroleum companies for the 1954-1975 period. The study examines the effect of vertical integration (measured in terms of the number of primary production processes in which these firms are involved) on basic, applied, and development research expenditures. Their results show positive and significant correlation between degree of vertical integration and the expenditures on each of the types of research expenditures.

Competition and uncertainty

Calderini and Garrone (2003a) present a rare analysis of the impact of liberalisation of network industries on innovative activities and examine the effect of telecommunication sector reform in Europe on innovative efforts of firms. The paper distinguishes between basic and applied research activities and measures their research output in number of publications and number of patents respectively. The study views liberalisation as an institutional discontinuity with competitive pressure and uses data from 17 former telecommunication monopolies that were subsequently liberalised. The results indicate that the anticipation and arrival of liberalisation resulted in a decline in publication activity while patenting activities increased. These findings are interpreted as indication that competitive pressure can lead to 'short-termism' at the expense of basic research that represents long-term benefits. In a related study Calderini (2001) discusses that sudden institutional discontinuity and subsequent imbalance between basic and applied research can even result in abandoning of all research activities.

Defeuilley and Furtado (2000) review the changes in R&D spending following the electricity reforms in the US and UK and reach a similar conclusion. The paper argues that restructuring and competition have not only resulted in an overall reduction in R&D expenditures, but have reoriented the balance toward short-term objectives and concrete applications that offer comparative advantage. At the same time, long-term research projects with potential radical outcomes and those requiring cooperation across generation, transmission, and distribution activities have become less attractive.

Sanyal and Cohen (2004) report a detailed econometric analysis of the effect of electricity sector restructuring in the US on utilities' R&D expenditure between 1989 and 1997. The findings indicate that the uncertainty associated with the reform process, measured as a deregulation index and probability of deregulation, has had a significant negative effect on the utilities' R&D expenditures. The level of "effective competition", measured as a weighted composite index based on 18 components, is also positively significant. However, some components of the competition index such as the "percentage of customers switching" supplier and "wholesale market model" are most directly associated with the actual competitive forces of the market place.

Also, another component of the index 'percentage of customers eligible for switching supplier' (rather as a firm-specific characteristic that can exert competitive pressure on firms) shows a significant and positive effect on R&D expenditures. The remaining components of the effective competition index essentially represent various regulatory measures that are undertaken in preparation for or to facilitate the reform and are discussed later. A notable aspect of the results for the components of the effective competition index is that some of these exhibit significant but opposing (positive and negative) effects on R&D expenditures. Further, the results show that firm size; bond rating; the share of industrial sales in total sales; and the level of regulatory concern with lower prices have positively significant effects on R&D spending. The importance of size is more profound when we note that the R&D spending of US utilities is rather concentrated. It should also be noted that the total R&D expenditures of US utilities during the period of the study were declining.

Jacquire-Roux and Bourgeois (2002) study the effect of liberalisation on the patenting activity of an international sample of large utilities (operators) and equipment suppliers in the electricity and petroleum sectors. They conclude that despite evidence of reduced R&D spending by operators and suppliers, the former industry shows a modest increase in patenting activities while the latter has achieved a considerable increase.

Joskow (2002) argues that the fact that electricity reform and market designs have frequently been modified has added to uncertainty in the sector. The effect of structural and uncertainty aspects of implementing reform, on innovation may be viewed in terms of level, direction, and rate of innovative activities. First, a one-off negative effect of restructuring and uncertainty can lead firms to adopt a lower level of R&D spending. In addition, restructuring renders parts of the pre-reform organisational knowledge and learning capacity irrelevant (Lomi and Larsen, 1999). Second, competition is likely to result in re-orientation of innovative efforts. Markard et al. (2004) in a survey of electric utilities observes a shift in the focus of R&D from technology based solutions to customer-oriented product and organisational innovations. Third, insofar as competition and uncertainty persist, R&D spending may consistently remain at a lower rate than otherwise.[4]

Firms engage in collaborative research for a variety of reasons and these have been studied from the perspective of transaction costs, industrial organisation, and strategic management (Hagedoorn, et al, 2000). Cohen and Sanyal (2004) analyse the effect of electricity sector restructuring on the US utilities' internal (in-house) and external (collaborative and outsourcing) R&D spending. They find that internal R&D declines with the initial uncertainty associated with reform but is positively significant with the arrival of actual competition. The study finds that a deregulation index (ranging between 0 and 3) has a negative and significant correlation with the internal R&D spending amounting to a marginal effect of 1.08 million at mean spending ($1.84 million) i.e., at mean spending, moving from one deregulation level to next reduces internal R&D by $US1.08 million. The effective competition score shows a negative correlation with external R&D spending. At the same time, a one percent increase in competition and probability of deregulation result in 0.08 and 22 percent increase in internal R&D spending respectively.

External R&D spending, however, increases with uncertainty from reform but declines when competition arrives. Deregulation index has a significant positive correlation with external R&D with a marginal effect of $1.55 i.e., at mean spending ($3.05 million), moving to next deregulation level increases external R&D by $US1.55 million. The effective competition score shows a negative correlation with external R&D spending. The coefficient for the introduction of a wholesale market is negative for internal R&D and positive for external R&D but neither is significant. The percentage of customers who switched supplier is negatively significant for internal and external R&D. The

[4] It should be noted that, even prior to reforms, the R&D intensity of the electricity industry has traditionally been lower than most other industries.

percentage of customers eligible for switching has a positive effect on external and internal R&D although it is only significant for the former. Moreover, several components of the effective competition index show significant but opposing effects on internal and external R&D expenditures. However, fewer of the components of the index exhibit a significant effect on utilities' total R&D expenditures.

Cohen and Sanyal (2004) state that failure to account for complementarity between internal and external R&D can result in underestimation of the former. The study finds that internal R&D has a positive and significant effect on external R&D and is not affected by the liberalisation process suggesting that internal R&D increases the ability of utilities to absorb or benefit from external R&D. The effect of external R&D on in-house R&D is, however, not significant. An additional benefit of collaborative R&D through major research organisations such as Electric Power Research Institute (EPRI) is that the industry will be able to exert influence on the R&D agenda and direction.

At the same time, the evidence on complementarity between government and industry funded R&D is, as surveyed in David et al. (2000), inconclusive. However, the survey shows that US based studies have less often found evidence of complementarity than the non-US studies. Mansfield and Switzer (1984) in a survey of four industries including electrical equipment find evidence of complementarity between government-funded and firm-funded energy R&D expenditures. The findings of the survey suggest that factors such as sales, percentage of energy R&D as total, and percentage of government-funded energy R&D analysis show a negative and significant effect on the firms' anticipated response to a cut in government-funded R&D. The study argues that the inter-firm variations can be explained by special government-funded projects in firms whose level affects the firm-funded R&D expenditures in the same direction. Also, Becker and Pain (2003) examine the determinants of low levels of R&D efforts in the UK during the 1990s. The study finds that reduction in government-financed R&D undertaken by private sector, weak output growth, and an increase in real effective exchange rate were the main reasons for decline in R&D outlay of the private sector.

The analysis of the factors comprising the weighted composite competition index in Sanyal and Cohen (2004) is illuminating. The results for the individual components of the index reveal the complexity of the task and multitude of factors likely to play a role when competition is introduced. In addition, the statistically significant factors point to different directions. Recalling the difficulties in implementing competition in the sector, it becomes evident that the notion that market forces would bring about the efficient level of R&D activity, which is not a central reform aim, has been somewhat optimistic.

The main justifications and driving forces of reform have little direct to do with promoting R&D and innovation.

Table 3 summarises the main findings of the literature reviewed in this section. As shown in the table, the main aspects of restructuring i.e. size reduction, unbundling, and competition and uncertainty are likely to have a negative effect on R&D spending and technology adoption. At the same time, competition and profit incentive will increase innovative output of the firms.

Table 3: Summary – Effect of restructuring on innovation

		Restructuring Aspect		
		Reduced Firm Size	**Reduced Vertical Integration**	**Increased Competition & Uncertainty**
Innovation Measure	**R&D Spending**	Multi-industry: (-) (Cohen & Kleppper, 96) Electric utilities: (-) (Wilder & Stansell, 74) (-) (Delaney & Honeycutt, 76) (-) Flynn and Mayo (1988) (-) Sanyal & Cohen, 04) (-) (Cohen & Sanyal, 04)	Petroleum: (-) (Armour & Teece, 80)	Electric utilities: (-) (Defeuilley & Furtado, 00) (-) (uncertainty) (Sanyal & Cohen, 04) (+) (Sanyal & Cohen, 04) (-) (uncertainty) (Cohen & Sanyal, 04) (+/-) (Cohen & Sanyal, 04)
	R&D Intensity		Multi-industry: (-) (Levy, 85)	
	R&D Spending – Complementarity and Trade-Offs			Multi-industry (incl. electric equipment): (+) (Govt. R&D on private R&D) (Mansfield & Switzer, 84) (Becker &Pain, 03) Electric utilities: (+) (internal R&D: on external R&D) (Cohen & Sanyal, 04) (-) (technology solutions: on customer & organisational solutions (Markard et al., 04)
	Innovation Output	Multi-industry: (+) (Cohen & Klepper, 96)		Telecoms: (-/+) (Calderini & Garrone, 03a) Electricity equipment suppliers: (+) (Jacquire-Roux & Bourgeois, 02)
	Technology Adoption	Electric utilities: (-) (Rose & Joskow, 90)		

3.2 Ownership – Privatisation and M&As

Historically, for both economic and political reasons, infrastructure industries have been largely under public ownership and control. Most reforms have involved some form of privatisation and private sector participation through the divestiture of assets or transfer of managerial control. In addition, following liberalisation, many private, privatised, and publicly owned utilities have engaged in domestic and cross-border M&As. This has even been true in the US where traditional privately owned utilities have experienced a large number of takeovers since 1992 (see Kwoka and Pollitt, 2005). Although there is an emerging body of literature on the various impacts of privatisation, including in the electricity sector, the R&D and innovation implications of ownership impacts of reform such as privatisation and mergers and acquisitions has generally not been addressed.

Privatisation

Privatisation is not a prerequisite for restructuring, the introduction of competition, or regulatory reform.[5] However, a combination of economic ideology and anticipation of proceeds from the sale has meant that privatisation has become a major reform step and, to some extent, has become an objective rather than a means to the end. Privatisation changes the characteristics of owners and corporate governance, and alters responses to external factors such as capital markets and regulators. The interaction between these internal and external factors in turn influence objectives and strategies for R&D and innovation.[6] Since privatisation has often been accompanied by the introduction of competition and regulation, it is difficult to separate out the effects of privatisation alone.

Many state-owned companies reduced R&D expenditures before privatisation in order to maximise government proceeds. The long-term nature of R&D expenditures, and the inherent uncertainty of outcomes, make these suitable candidates for quick cost cutting, so increasing short-term profitability (Munari and Sobrero, 2003b). For example, some privatisation programmes in the European Union countries coincided with their governments' need to reduce public deficits in order to comply with the fiscal requirements of European monetary union (Easterly and Servén, 2003).

[5] In Norway, the electricity reform did not involve privatisation of the sector dominated by a large number of state, county, and municipality owned utilities. Elsewhere, at the time of reform in the US or Japan private ownership was already the dominant mode of ownership.

[6] See Munari and Sobrero (2003a) for a review of the role of corporate governance in innovative activities.

Munari and Sobrero (2003b) look at the effect of privatisation on R&D and patent activity for 35 privatised European companies from 11 industries. The study finds that R&D expenditure is significantly and positively correlated with size, privatisation (dummy variable), and leverage, but is negatively correlated with the private share in the company. Also, R&D intensity of the firms are significantly and positively correlated with privatisation and significantly negatively correlated with private share in these firms. In addition, the study finds some evidence of the positive effect of privatisation and private ownership share in the firms on patenting activity. Further, the results show that R&D spending of regulated monopolies is negatively and significantly correlated with the privatisation. This is in line with indications from the electricity distribution utilities, most of which have been subject to incentive regulation following privatisation. Regulators adopting incentive regulation have been mainly concerned with making the new regulatory regime work; promotion of R&D activities has not been a priority. In the absence of explicit and targeted incentives, many utilities have significantly reduced their R&D spending. The electricity regulator in Britain has recently taken steps to reverse this through establishing an Innovation Funding Incentive of 0.5% of the revenue of regulated electricity distribution companies (Ofgem, 2004).

Gugler (2003) reports an econometric analysis of R&D expenditure, dividends, and investments for a panel of 214 Austrian firms from various industries (consisting of state, family, bank, and foreign owned firms) using a simultaneous system of equations for the 1991-99 period. The results suggest that, for R&D-spending firms, investments and R&D are mutually, significantly and negatively correlated indicating internal competition for funds. In addition, R&D spending and dividends are mutually, negatively though not significantly correlated, while investments and dividends are significantly and negatively correlated and therefore compete for funds. The study also finds that R&D expenditures are positively correlated with the firms' balance of cash, size (measured in sales), and number of patents for which they applied.

The study does not explicitly examine the effect of ownership type on R&D expenditure, but it reports that these firms, more than one-third of which are publicly owned companies utilities (mostly electric utilities) are most likely to engage in dividend smoothing and most reluctant to cut dividends. It is conceivable that many newly privatised companies face an increased level of internal competition for funds similar to the firms in this study.

Munari et al. (2002) presents a theoretical framework for how economic, political, and cognitive factors associated with privatisation can lead to profound changes in the organisation and objectives of R&D in privatised firms. The main changes occur in the form of reductions in R&D expenditures, a shift towards applied and commercial projects, and restructuring of collaborative activities. The study examines four privatised companies, including the partial privatisation of ENEL, the Italian state-owned electricity company. The change in the company's operating environment and shift of R&D focus is reflected in the company's mission statement before and after privatisation and is indicative of this transformation. The pre-privatisation mission statement, with regards to R&D, emphasises "…technical and scientific progress of the Italian electricity system…" while the aim of the post-privatisation statement is "to directly contribute to company competitiveness focusing on innovative solutions…".

In response to vertical separation of ENEL's generation, transmission and distribution activities, the corporate R&D efforts were redefined along the lines of these now distinct areas of business. R&D allocation as a share of total corporate sales declined from 2.2 percent to 1.8 percent, and the share of long-term R&D projects fell from 60 to 20 percent of the total. The share of R&D projects funded by operating divisions rose from 40 to 80 percent.

The increased focus on applied and short-term research, combined with emphasis on commercialisation of research results, evidently led to an increase in patent activity. In a similar study of the privatisation of the same four firms above and two French firms, Munari (2003) shows that, in general, these firms exhibited an increase in their post-privatisation innovative output measured in terms of number of patents per researcher. It is conceivable that increased commercial orientation and patent activity in privatised firms also leads to faster adoption of new technologies. Rose and Joskow (1990) in their analysis of US electric utilities find that private utilities were more likely to adopt two new generation technologies and co-operative and government owned utilities had lower hazard rate between 44 and 51 percent.

Electricity sector privatisation and reform has occurred at a time when theory and empirical evidence on the relative efficiency of public vs. private ownership in general, and in the sector in particular, is inconclusive (Jamasb et al, 2004; Pollitt, 1995). Privatisation of generation and supply activities has often been followed by introducing competition in the wholesale and retail markets, while privatisation of transmission and distribution networks has involved independent regulation. The effect of privatisation of the electricity industry in the UK on the firms' R&D spending sheds some light on this.

More than a decade since the liberalisation in 1990, the R&D spending of major non-nuclear generators continued to decline in the 2000s (DTI, 2004).

For the transmission network owner and operator NGC, R&D spending has decreased significantly.[7] Moreover, R&D intensity measured as R&D spending as a percentage of turnover for the fourteen distribution network operators in the UK, in 2001-2 and 2002-03, has been estimated at 0.1 percent. This compares to 2.5 percent R&D intensity for GDP as a whole (OFGEM, 2004). In the generation market, the new private entrants as independent power producers (IPPs) do not seem to engage in R&D efforts. In addition, the major UK generators have, since late 1980s, considerably reduced their R&D engagements (MacKerron and Watson, 1996) and cut these by at least 45% between 1988/9 and 1994/5 (Eurelectric, 2002).

Mergers and acquisitions

The liberalisation trend began in the early 1990s in the UK, Norway and New Zealand and, by late 1990s, many developed and developing countries were reforming their electricity sectors. Within a few years, a market for electricity assets at domestic, regional, and global levels emerged. Indeed, the new market for electricity assets appeared to develop faster than the electricity product market itself.

The new entities emerging from unbundled firms needed to devise strategies suitable for their new operating environment. An important part of such strategies was how to position the firm in the new global market place and (re)match their assets in the light of the new threats and possibilities. A wave of M&As followed in the aftermath of the liberalisations in which even some state-owned companies participated and expanded beyond their domestic and regional markets. It is unclear whether privatisation generally results in higher leverage. However, the post-privatisation capital requirements for new investment and acquisitions are likely to lead to higher levels of leverage. Higher leverage level and cost of capital to private owners can result in more internal competition for funds between R&D and other spending.

There are no specific empirical studies on the effect of electricity sector M&As, but there is a body of literature on how M&As impact a firms' innovative activities. Calderini and Garrone (2003b) review the recent literature (see also Cassiman et al., 2004) and point to a negative relationship between financial leverage and R&D intensity. The possible reasons for this are that some firms that are privatised or are

[7] It should be noted that NGC's R&D expenditures are subject to regulatory approval.

subject to competition, need to undertake financial restructuring or engage in mergers that result in a higher level of leverage.

Hall (1990), in a study of corporate restructuring in the US manufacturing industries between 1982 and 1987, finds that increased leverage had a significant and negative correlation with R&D spending. Moreover, the results show limited support for the hypothesis that R&D intensity declines as a result of acquisitions, and concludes that the small declines observed are due to increased leverage rather than to acquisitions. This result, however, contrasts with finding of NSF (1989) that among the top 200 R&D-spending firms between 1984 and 1986, 24 were involved in mergers or restructuring and their R&D spending declined by 5.3 percent, while spending of other firms in the sample increased by 4.5 percent.

Also, Calderini, et al. (2003) study 19 US firms in the information and communications technology industries acquired between 1989 and 1992. The findings suggest that after acquisitions, mostly horizontal and technologically unrelated, the innovative output of targeted firms in terms of patenting activity declined relative to a control group of non-acquired firms. Hitt et al. (1991) found that acquisitions have a negative impact on R&D intensity and patent intensity of acquiring firms. In addition, diversifying acquisitions showed a negative impact on patent intensity.

Calderini and Garrone (2003b) review the evidence on the effect of economies of scale and scope (i.e. M&As involving similar and diverse firms respectively) on R&D. The evidence on effect of scale economies on R&D suggests “neutral/negative effect on the input side and a positive/neutral effect on the output side”. Moreover, the evidence on economies of scope generally shows positive effect from diversifying acquisitions, possibly due to positive externalities. This finding is also relevant for electric utilities, as these have engaged in vertical and horizontal as well as diversifying M&As with other infrastructure industries (e.g. gas and water), to benefit from the perceived synergies of multi-utilities.

Cassiman et al (2004) view the effects of M&As on R&D with a view of technological and market relatedness between acquiring and acquired firms. The paper surveys 31 cases of M&As to examine the effect of technological complementarity vs. substitution and rivalry vs. non-rivalry of the parties in mergers on R&D performance and a set of measures of R&D process. The study finds that the mergers between technologically complementary firms show higher (not significant) R&D activity while technologically substitutive firms reduce R&D significantly. Increases in R&D efficiency are larger in mergers with technologically complementary firms than those with substitutive technologies. Merging rival firms are less likely to enter new R&D areas, while non-rival firms show higher R&D output and productivity than merging rival firms. For technologically substitutive merging firms, the R&D decline is larger and the R&D efficiency gain is smaller for merging rival firms than it is for non-rival firms. A related question follows as to whether cross-border M&As in the electricity sector have also contributed to the decline in R&D activities. Shen and Reuer (2004) in a study of acquisition of entrepreneurial firms, show that there is a significant negative correlation between the spatial dispersion of the firms and R&D intensity. It may be that mergers are cutting out wasteful duplication of R&D expenditure.

Sanyal and Cohen (2004) in analysis of the R&D expenditure in the US investor-owned utilities between 1989 and 1997, find that the dummy variable for pending mergers showed a significant and negative impact on the probability of firms deciding to engage in R&D. Cohen and Sanyal (2004) find that pending mergers have a negative impact on internal R&D expenditures and a positive effect on external R&D expenditures, although these are insignificant in both cases.

Table 4 summarises the main findings of the literature on innovation and ownership discussed in this section.

Table 4: Summary – innovation and ownership

		Ownership Aspect		
		Increased Privatisation & Private Ownership	**Increased Mergers & Acquisitions**	**Increased Leverage, Investment, Dividend, etc.**
Innovation Measure	**R&D Spending**	Multi-industry: (+/-) (Munari & Sobrero, 03b) Privatised regulated monopoly: (-) (Munari & Sobrero, 03b) (-) Munari et al., 02)	Multi-industry: (-) (NSF, 89) Survey: (-/neutral) (Calderini & Garrone, 03b) (-/+) (Calderini et al, 03) Electric utilities: (-) (Sanyal & Cohen, 04)	Multi-industry: (+) (Munari & Sobrero, 03b). (-) Investments & dividends (Gugler, 03) (+) Balance of cash (Gugler, 03) (-) Leverage (Hall, 90)
	R&D Intensity	Multi-industry: (+) Privatisation (Munari & Sobrero, 03b). (-) Private share (Munari & Sobrero, 03b)	Survey: (-) M&As (leverage effect) (Calderine & Garrone, 03b) Multi-industry: (-) (Hitt, et al., 91) (-) (Shen & Reuer, 04)	Multi-industry: (-) (Munari & Sobrero, 03b)
	R&D Activity	Multi industry: (+) applied/commercial R&D (Munari et al., 02)		
	Patenting Activity	Multi-industry: (+) (Munari & Sobrero, 03b) (+) (Munari, 03)	Multi-industry: (-) (Calderini et al, 03) (-) (Hitt, et al., 91). (+) (Calderini & Garrone, 03b)	Multi-industry: (+) (Gugler, 03)
	New Technology Adoption	Electric utilities: (+) (Rose & Joskow, 90)		

3.3 Regulation

Reform-relevant literature on the effect of regulation on R&D and innovation is somewhat limited due to the fact that, in most countries prior to the introduction of reforms, the notion of independent regulation did not exist. The largest share of the existing literature is within the context of utility regulation in the US where there is a long-established tradition of privately-owned infrastructure industries subject to independent federal and state level regulation. But even in the US, due to differences in the restructuring of the industry, it is rather difficult to learn from the insights of the empirical literature and conceptualise the possible overall R&D effects of the reform-related regulatory changes.

A few studies have focused on the effects of regulation on technical change in the electricity sector. Technical change may be regarded as an observable measure or indicator of performance or outcome of R&D input and output, diffusion, and innovation adoption. Smith (1974) extends the Averch-Johnson theoretical model of regulated firm to show that ROR regulation not only offers incentives to over-capitalise, but can also lead to the adoption of labour augmenting technologies and under-investment in capital augmenting technologies.[8] However, the paper points out that, to the extent that regulated firms are not vertically integrated in R&D i.e. they cannot exert control over the innovation agenda, this effect may be reduced. The paper argues that in the US electricity industry where most R&D was undertaken by equipment manufacturers and the federal government, the rate of technical change was faster than in other industries.

Frank (2003) analyses the technical change in electric utilities in Texas before and after the transition from loose local and municipal regulation to state ROR regulation in 1975. The study estimates technical progress at 1.24% per year between 1965 and 1974, as opposed to a technical regress at -0.72% per year between 1975 and 1985 after the introduction of ROR regulation. Frank (2003) is in agreement with the model in Smith (1974) and finds evidence of over-capitalisation and adoption of labour augmenting technologies in the utilities. Granderson (1999) examines the effect of regulation on 20 US inter-state natural gas pipeline companies against the case of a theoretical deregulation of the industry, and finds that regulation results in adoption of non-capital augmenting technologies and a small decline in the rate of technical change.

Nelson (1984) estimates the effect of capital vintage and regulation on technical change in the US electric utilities between 1951 and 1978, and finds that the dominating share of technical change stems from capital vintage represented by a vintage index and time trend variable. The effect of regulation, however, measured as allowed rate of return (ROR), appears to be very small. The study suggests that policies favouring specific types of generation technologies have been more effective than ROR regulation in promoting R&D.

In two studies of the innovation efforts of the US electricity utilities between 1968 and 1972, Wilder and Stansell (1974) and Delaney and Honeycutt (1976) examine whether the type of regulation affects the utilities' R&D outlays. Both studies report that the dummy variable representing type of regulation, i.e. state versus municipal level

[8] Westfield (1971) uses a different approach to modelling resource augmentation under regulation, which indicates that over-capitalisation tendency among rate of return regulated firms also extends to a preference for capital augmenting technologies.

oversight is insignificant. Mayo and Flynn (1988) examine the effect of regulation on R&D in US electric utilities for 1975 and 1983. The regulation variables used are allowed ROR and a dummy variable for whether R&D spending have been allowed in the rate base in order to represent the lower and upper end of distribution of returns to R&D respectively. The results for 1983 shows that both variables are positively significant and each point increase in ROR on common equity (at mean level) showing an estimated elasticity of 1.07. For 1975, the allowed ROR, which could be regarded as non-binding i.e. utilities could (and as many did) earn a lower than granted rate of return, is not significant.

Bailey (1974) using a model shows that innovative activity of a regulated firm increases with the length of regulatory lag, but it will take longer for the society to benefit from the progress. The results suggest that while increased ease of innovation encourages innovative activity, higher cost of research and higher discount rate will reduce it. Also, higher elasticity of demand requires longer regulatory lags to promote innovative activity. In a related paper, Sweeney (1981) shows by way of a model, that regulated firms may slow down or choose the timing for adoption of innovation to increase profits across the regulatory lag. This incentive property of the regulatory lag is not restricted to savings from innovation and can apply to timing of cost savings in general. It should be noted that propensity of regulatory lags to encourage strategic behaviour in the form of timing cost savings is rather similar under both ROR and price cap regulation.[9]

Although some innovation properties of ROR regulation have been examined, the relative effect of ROR versus price cap regulation on the rate of technical change has not been studied in detail. Magat (1976) uses a conceptual model to compare the rate of technical change under ROR, ceiling price, and mark-up regulation regimes, and shows that ceiling price regulation results in a faster rate of technical progress than under no regulation and mark-up regulation.[10] In addition, with Hicks-neutral technical change, the rate of innovation under ceiling price regime will be higher than under ROR regulation. Cohen and Sanyal (2004) show that performance-based pricing (in the form of a ceiling price and/or ROR regulation with profit sharing hybrid for network utilities) and divestiture of generation assets have both negative and significant effects on utilities' internal and external R&D expenditures.

---

[9] For example, the UK electricity regulator Ofgem has estimated that, under the current distribution price control, companies retain 27% of the present value of a cost reduction made in the first year of a control period but only 6% of the present value of an equal cost saving made in the final year (Ofgem, 2003).

[10] Here, the ROR regulation assumes that the regulator sets the maximum allowed return. Ceiling-price regulation assumes a regulated price lower than unconstrained monopoly price but high enough to allow a nonnegative profit and promotes cost minimisation. Markup regulation assumes a maximum permissible markup on total costs that is lower than the markup earned by an unconstrained profit maximising firm.

Engaging in R&D and adopting new technologies requires capital expenditure. At the same time, the Averch-Johnson effect tends to result in over-capitalisation under rate of return regulation. Similarly, allowing for inclusion of R&D outlays in the rate base is expected to lead to higher R&D efforts as it reduces financial risk. We have also seen indications of a positive effect of allowed ROR on R&D outlays. However, increasing ROR is not an effective policy tool to induce technical progress as its effect on innovation is indirect.

There is an increase in the use of the price cap regulation model for regulating electricity networks. In liberalised electricity sectors, only distribution and transmission networks tend to be subject to price cap regulation. The best-known example of the use of price cap regulation in electricity networks is the case of the UK sector. Capital expenditure plans by utilities, arguably the most relevant spending item for R&D, require regulatory approval in the UK. Therefore, while price caps in principle can encourage R&D, the current model does not explicitly promote this incentive.

It is conceivable that, under a price cap, companies will first attempt to achieve cost-savings through managerial and organisational efforts. However, over time the X-inefficiency is reduced. Having utilised these sources of efficiency improvement, technical change is increasingly the likely source of long-term efficiency improvement. Some of the main areas in which post-reform network systems are in need of technical progress are quality of service, distributed generation, and intermittency of some new generation sources. An issue here is whether some companies will free ride on other companies' long term risky investments knowing that much of the knowledge generated is likely to be diffused quickly. Table 5 summarises the main findings discussed in this section.

Table 5: Summary – innovation and regulation

		Regulation Aspect		
Innovation Measure		**ROR Regulation as Policy Tool**	**State vs. Local Regulation**	**Introduction of Incentive Regulation and Lengthening of Regulatory Lag**
	R&D Spending	Electric utilities: (+) Technology policy more effective than ROR (Nelson, 84) (+) (R&D in rate base) (Mayo & Flynn, 88)	Electric utilities: (-/neutral) (state regulation (Wilder & Stansell, 74; Delaney & Honeycutt, 76)	Electric utilities: (-) Incentive regulation (Cohen & Sanyal, 04)
	Innovative Activity			Model: (+) (regulatory lag) (Bailey, 74) (+) (regulatory lag) (Sweeney, 81)
	Adoption of New Technology	Model: (+) (labour augmenting technologies), (-) capital augmenting technologies (Smith, 74). Electric utilities: (+) (labour augmenting technologies), (-) capital augmenting technologies (Frank, 03) Gas pipelines: (+) (non-capital augmenting technologies) (Granderson, 99)		
	Technical Change	Electric utilities: (+/small) (Nelson, 84)	Electric Utilities: (-) (state regulation) (Frank, 03; Granderson, 99)	Model: (+) ceiling-price (Magat, 76)

4. Conclusions

This paper has examined the likely structural origins of the decline in R&D spending that resulted from electricity reform. Technical progress has been on the margins of the electricity reform process, and has neither constituted a driving force nor an objective. The anticipation of positive effects from deregulation on innovative efforts has been indirect and implicit, and therefore ‘uncertain’. Our examination of the theory and evidence suggests that the decline in R&D spending in the electricity sector was predictable. Indeed with hindsight, it can be claimed that the pre-reform literature contained sufficient indications to predict a reduction in energy R&D spending.

By introducing competition and unbundling and by extending private ownership in the electricity sector, liberalisation has subjected the industry to the generally recognised incidence of market failure in R&D spending. We identified several dimensions to the causes of decline in R&D in the sector. These include the negative effect of size where large firms are split up and activities are separated. Market competition and increased uncertainty, at least initially, also lead to lower R&D spending levels. It is too early to judge whether, in the long-term, the industry will find a sufficiently profitable private return in R&D to justify a higher level of expenditure than at present.

To the extent that privatisation has lead to increased leverage and pressure for short-term profitability, these are likely to have contributed to a cut back in R&D spending budgets. Mergers and acquisitions have likely had the same effect, though vertical mergers provide a notable exception. In addition, the incentive properties and regulatory lag in price cap regulation, often implemented in conjunction with reform, are not likely to promote R&D investment unless these enter the asset base.

Reduction in government R&D spending is likely to result in less private R&D which in turn leads to lower in-house and collaborative R&D spending. We also saw that intra-firm competition for resources between investments, dividend and R&D is likely to disfavour the latter. Collectively, in many instances, the above factors result in lower private returns of many R&D programs than social and/or profitable returns.

At the same time, R&D productivity and innovative output per unit of input, such as patenting and organisational adjustment, appears to have improved. This finding is both intuitive and in line with general improvements in the operating efficiency of the sector. Despite this apparent increase in innovative outputs, a lasting decline in basic R&D and innovation input in basic research may negatively affect development of radical technological innovations in the long run.

Policy implications

A simple remedy to market failure in basic research and development and diffusion stages of the innovation process, as in other vital industries, is through positive intervention. The issue is how to do adapt this to the needs of the electricity industry without returning to some of the well known problems of the past such as the strong bias in the UK to wasteful domestic nuclear R&D expenditure widely acknowledged to have not produced long term benefits (see Henderson, 1977 and Green, 1995).

The exact nature of government intervention aimed at the promotion of technical progress remains elusive and the subject of extensive debate. However, in the light of wide-ranging reform-related structural, market, governance, and ownership changes, government intervention in market-oriented settings will need to be different from those in pre-reform settings. There are good reasons to think that, for the foreseeable future, competitive electricity markets will deliver sub-optimal amounts of R&D input and output. There is, therefore, a need for reorientation of energy technology policies towards more basic research and public private partnerships.

As discussed in Fri (2003), it is inherently difficult for the government to pick the winning energy technologies. Successful technologies are generally incremental rather than disruptive, and this suggests that intervention could be more effective when aimed at removing specific obstacles to technical progress rather than following broad base policies. Government programmes may, in some cases, be able to introduce a technology to the market and promote its diffusion through regulation and other measures. The challenge is, however, to promote R&D in ways that can harness the power of the private sector to minimise development costs and to select good projects.

Liberalisation has shown that the post-reform industry responsive to incentives – both to profit incentive in competitive activities and those of incentive regulation of natural monopoly networks. Many types of R&D in the electricity industry require large-scale and long-term program that can best be achieved through collaborative research. Public support and incentives can be effective at promoting socially desirable programs and contribution to and participation in joint efforts. The tendency among some governments has been to finance subsidies for promotion of renewable energy from special taxes on electricity rather than from general taxation. This approach can be also extended to financing subsidies to promote R&D. The recent policy by the regulator in Britain earmarking one-half percent of distribution utility revenues for innovation programs is an example in case.

As we noted, R&D active firms tend to be more efficient, and more firms (incl. manufacturers) should be made R&D active. Government intervention should, where possible, promote internal and collaborative effort. In addition, market forces and trends in technical progress need to be assessed continuously for possible intervention. Some levels of R&D tax credits and subsidies can stimulate private R&D though large subsidies may crowd out private R&D spending.

Finally, there is a need for more empirical research to determine whether the changes in innovative activity are a temporary or a lasting feature of deregulation. We also need to enhance our understanding of innovation in general and how to promote innovation in deregulated network industries in particular.

References

Armour, H. O. and Teece, D. J. (1980). Vertical integration and technological innovation, *The Review of Economics and Statistics*, Vol. 62, No. 2, August.

Arrow, K. J. (1962). The economic implications of learning-by-doing, *The Review of Economic Studies*, Vol. 29 (June), Issue 3, 155-173.

Bailey, E. E. (1974). Innovation and regulation, *Journal of Public Economics*, Vol. 3, 285-295.

Becker, B. and Pain, N. (2003). What determines industrial R&D in the UK?, National Institute of Economic and Social Research, April, London.

Bell, R. and Seden, W. (1998). Utility restructuring and the transformation of industry-sponsored R&D, *The Electricity Journal*, Vol. 11, Issue 10, 32-39, December.

Bell, R. A. and Schneider, T. R. (1999). Balkanization and the future of electricity R&D, *The Electricity Journal*, Vol. 12, Issue 6, 87-98, July.

Calderini, M. and Garrone, P. (2000). On-linear dynamic effects in the composition of R&D, *Quaderni di Economia*, No. 3/2000, Polytechnic University of Turin, Turin, Italy.

Calderini, M. and Garrone, P. (2003a). Liberalization and the balance of R&D activities: An empirical analysis, in Calderini, M., Garrone, P. and Sobrero, M., eds., Corporate Governance, Market Structure and Innovation, Edward Elgar: Cheltenham.

Calderini, M. and Garrone, P. (2003b). Mergers and acquisitions and innovation strategies, in Calderini, M., Garrone, P. and Sobrero, M., eds., Corporate Governance, Market Structure and Innovation, Edward Elgar: Cheltenham.

Calderini, M., Garrone, P., and Scellato, G. (2003). The effects of M&A on the innovation performance of acquired companies, in Calderini, M., Garrone, P., and Sobrero, M., eds., Corporate Governance, Market Structure and Innovation, Edward Elgar: Cheltenham.

Cassiman, B., Colombo, M., Garrone, P., and Veugelers, R. (2004). The impact of M&A on the R&D process: An empirical analysis of the role of technological and market relatedness, *Research Policy* (forthcoming).

Chang, H.J., ed. (2003). *Rethinking Development Economics*, Anthem: London.

Christensen, L. R. and Greene, W. H. (1978). An econometric assessment of cost savings from coordination in US electric power generation, *Land Economics*, 54, 139-155.

Cohen, W. M. and Klepper, S. (1996). A reprise of size and R&D, *The Economic Journal*, Vol. 106, No. 437, July, 925-951.

Cohen and Sanyal (2004). R&D choice in restructured industries: In-house v/s collaborative research in the US electricity industry, March.

Cohen, W. M. and Levin, R. C. (1989). Empirical studies of innovation and market structure, in Schmalensee, R. and Willig, R. D., eds., Handbook of Industrial Organization, North-Holland: Amsterdam.

Cramer, C. and Tschirhart, J. (1983). Power pooling: An exercise in industrial coordination, *Land Economics*, 59, 24-34.

David, P. A., Hall, B. H., and Toole, A. A. (2000). Is public R&D a complement or substitute for private R&D? A review of the econometric evidence, *Research Policy*, Vol. 29, 497-529.

Defeuilley, C. and Furtado, A. T. (2000). Impacts de l'ouverture à la concurrence sur la R&D dans le secteur électrique, *Annals of Public and Cooperative Economics*, 71:1, 5-28.

De Fraja, G. (1993). Productive efficiency in public and private firms, *Journal of Public Economics*, Vol. 30, 15-30.

Delaney, J. B. and Honeycutt, T. C. (1976). Determinants of research and development activity by electric utilities: Comment, *The Bell Journal of Economics*, Vol. 7, Issue 2, 722-725.

Domah, P. D. and Pollitt, M.G. (2001). The Restructuring and privatisation of the regional electricity companies in England and Wales: A social cost benefit analysis, *Fiscal Studies*, Vol.22, No.1, 107-146.

Dooley. J. J. (1997). Unintended Consequences: Energy R&D in a Deregulated Market. Pacific Northwest National Laboratory, PNNL-SA-28561, Washington, D.C. February.

DTI (2004). UK Department of Trade and Industry, R&D Scoreboard 2004 and Database, accessed at http://www.innovation.gov.uk/projects/rd_scoreboard/introfr.html

Easterly, W. and Servén, L. (2003). Introduction, in Easterly, W. and Servén, L., eds., The Limits of Stabilization: Infrastructure, Public Deficits, and Growth in Latin America, The World Bank, Washington, D.C.

Eurelectric (2003). R&D in EURELECTRIC Countries, 2002 Update, Research and Development Working Group, Ref: 2002-520-0013, Union of the Electricity Industry, January, Brussels.

Eurelectric (1998). R&D in UNIPEDE Countries: Overview of R&D Organisation and Projects, 1998 update, Research & Development Working Group, Ref: 1998-150-0005, Union of the Electricity Industry, December.

FEPCO/CEPC (2004). Japanese Electricity Industry Research and Development, The Federation of Electric Power Companies and The Central Electric Power Council.

Ferguson, P. R. and Ferguson, G. J. (1994). Industrial Economics: Issues and Perspectives (2nd ed.), Macmillan: London.

Frank, M. W. (2003). An empirical analysis of electricity regulation on technical change in Texas, *Review of Industrial Organization*, Vol. 22, 313-331.

Fri, R. W. (2003). The role of knowledge: Technological innovation in the energy system, *The Energy Journal*, Vol. 24, No. 4, 51-74.

Galal, A., Jones, L., Tandon, P., and Vogelsang, I. (1994). Welfare Consequences of Selling Public Enterprises: An Empirical Analysis, Oxford University Press, Oxford.

GAO (1996). Changes in Electricity-Related R&D Funding, General Accounting Office, GAO/RCED-96-203), August.

Gagax, D. and Tschirhart, J. (1984). An analysis of interfirm cooperation: Theory and evidence form electric power pools, *Southern Economic Journal*, 50, 1077-1097.

Gilsdorf, K. (1995). Testing for subadditivity of vertically integrated electric utilities, *Southern Economic Journal*, Vol. 62, 126-138.

Gilsdorf, K. (1994). Vertical integration efficiencies and electric utilities: A cost complementarity perspective, *Quarterly Review of Economics and Finance*, Vol. 34, 261-282.

Granderson, G. (1999). The impact of regulation on the technical change, *Southern Economic Journal*, Vol. 65(4), 807-822.

Green, R. (1995). The cost of nuclear power compared with alternatives to the Magnox programme, *Oxford Economic Papers*, Vol. 47, 513-524.

Grubb, M., Kohler, J., and Anderson, D. (2002). Induced technical change in energy and environmental modelling: Analytic approaches and policy implications, *Annual Review of Energy and Environment*, 27, 271-308.

Gugler, K. (2003). Corporate governance, dividend payout policy, and the interrelation between dividends, R&D, and capital investment, *Journal of Banking & Finance*, Vol. 27, 1297-1321.

Hagedoorn, J., Link, A. N., and Vonortas, N. S. (2000). Research partnerships, *Research Policy*, Vol. 29, 567-586.

Hall, B. H. (1990). The impact of corporate restructuring on industrial research and development, Brookings Papers on Economic Activity. Microeconomics, Vol. 1990, 85-124.

Hart, O., Shleifer, A., and Vishny, R. W. (1997). The proper scope of government: Theory and application to prisons, *Quarterly Journal of Economics*, Vol. 112, No. 4, 1127-1158.

Hattori, T. (2005). Liberalization and R&D in Japanese Electricity Industry - An Initial Observation of Patent Data, paper presented at 28th Annual International Association of Energy Economists (IAEE) Conference, Taipei, June 3-6.

Hayashi, P. M., Goo, J.Y.-J., and Chamberlin, W. C. (1997). Vertical economies: The case of US electric utility industry, 1983-1987, *Southern Economic Journal*, Vol. 63, No. 3, 710-725.

Henderson, P. D. (1977). Two British errors: Their size and some possible lessons, *Oxford Economic Papers*, Vol. 29, Number 2, 159-205, July.

Hirch, R. F. (1999). Power Loss: The Origins of Deregulation and Restructuring in the American Electric Utility System, The MIT Press: Cambridge, Mass.

Hitt, M. A., Hoskisson, R. E., Ireland, R. D., and Harrison, J. S. (1991). Effects of acquisitions on R&D inputs and outputs, *Academy of Management Journal*, Vol. 34, No. 3, 693-706.

Huettner, D. A. and Landon, J. H. (1978). Electric utilities: Scale economies and diseconomies, *Southern Economic Journal*, 44, 883-912.

Hughes, W. R. (1971). Scale frontiers in electric power, in Capron, W. M., ed., Technological Change in Regulated Industries, The Brookings Institution: Washington, D.C.

IEA (2004a). Energy Policies of IEA Countries – 2004 Review, International Energy Agency, Paris.

IEA (2004b). Renewable Energy: Market & Policy Trends in IEA Countries, International Energy Agency, Paris.

IEA (1999). Electric Power Technology: Opportunities and Challenges of Competition, International Energy Agency, Paris.

Jacquier-Roux, V. and Bourgeois, B. (2002). New networks of technological creation in energy industries: Reassessment of the roles of equipment suppliers and operators, *Technology Analysis and Strategic Management*, Vol. 14, No. 4, 399-417.

Jamasb, T., Mota, R., Newbery, D., and Pollitt M. (2005). Electricity sector reform in developing countries: A survey of empirical evidence on determinants and performance, World Bank Policy Research Working Paper 3549, World Bank, Washington, DC.

Jamasb, T. (2002). Reform and regulation of the electricity sectors in developing countries, Working Paper DAE 0206/CMI EP 08, Department of Applied Economics, University of Cambridge.

Joskow, P. L. (1998). Electricity sectors in transition, *The Energy Journal*, Vol. 19, No. 2, 25-52.

Joskow, P. L. (2002). Electricity sector restructuring and competition: A transactions-cost perspective, in Broussau, E. and Glachant, J.-M., eds., The Economics of Contracts: Theories and Applications, Cambridge University Press: Cambridge.

Kamien, M. I. and Schwartz, N. L. (1975). Market structure and innovation: A survey, *Journal of Economic Literature*, Vol. 13, No. 1, March, 1-37.

Kaserman, D. L. and Mayo, J. W. (1991). The measurement of vertical economies and the efficient structure of the electric utility industry, *The Journal of Industrial Economics*, Vol. 39, No. 5, 483-502, September.

Kouvaritakis, N., Soria, A., Isoard, S. (2000). Modelling energy technology dynamics: methodology for adaptive expectations models with learning by doing and learning by searching, *International Journal of Global Energy Issues* 14 (1-4) 104-115.

Kwoka, J. and Pollitt, M. (2005). Restructuring and efficiency in the U.S. electric Power sector, Cambridge Working Papers in Economics, Faculty of Economics, University of Cambridge (forthcoming).

Lee, B.-J. (1995). Separability test for the electricity supply industry, *Journal of Applied Econometrics*, Vol. 10, 49-60.

Levy, D. T. (1985). The transaction cost approach to vertical integration: An empirical examination, *The Review of Economics and Statistics*, Vol. 67, No. 3, 438-445, August.

Lomi, A. and Larsen E. (1999). Learning without experience: Strategic implications of deregulation and competition in the electricity industry, *European Management Journal*, Vol. 17, No. 2, 151-163.

MacKerron, G. and Watson, J. (1996). The winners and losers so far, in Surrey, J., ed., The British Electricity Experiment: The Record, the Issues, the Lessons, Earthscan: London.

Magat, W. A. (1976). Regulation and the rate and direction of induced technical change, *The Bell Journal of Economics*, Volume 7, No. 2, Autumn, 478-496.

Mansfield, E. and Switzer, L. (1984). Effects of federal support on company-financed R and D: The case of energy, *Management Science*, Vol. 30, No. 5, May, 562-571.

Margolis, M. and Kammen, D. M. (1999). Underinvestment: The energy technology and R&D policy challenge, *Science*, Vol. 285, 690-692, July.

Markard, J., Truffer, B., and Imboden, D. M. (2004). The impacts of liberalisation on innovation processes in the electricity sector, *Energy & Environment*, Vol. 15, No. 2, 201-214.

Markiewicz, K., Rose, N. L., and Wolfram, C. (2004). Does competition reduce costs? Assessing the impact of regulatory restructuring on U.S. electric generation efficiency, Cambridge Working Papers in Economics CWPE 0472 / CMI Working Papers CMI EP 67, Faculty of Economics, University of Cambridge.

Mayo, J. W. and Flynn, J. E. (1988). The effects of regulation on research and development: Theory and evidence, *The Journal of Business*, Vol. 61, Issue 3, July, 321-326.

Megginson, W.L. and Netter, J.M. (2001). From the state to the market: A survey of empirical studies on privatisation, *Journal of Economic Literature*, Vol.39, 321-389.

Munari, F. (2003). The organization of R&D activities within privatized companies, in Calderini, M., Garrone, P., and Sobrero, M., eds., Corporate Governance, Market Structure and Innovation, Edward Elgar: Cheltenham.

Munari, F., Roberts, E. B., Sobrero, M. (2002). Privatization processes and the redefinition of corporate R&D boundaries, *Research Policy*, Vol.31, 31-53.

Munari, F. and Subrero, M. (2003a). Corporate governance and innovation, in Calderini, M., Garrone, P., and Sobrero, M., eds., Corporate Governance, Market Structure and Innovation, Edward Elgar: Cheltenham.

Munari, F. and Subrero, M. (2003b). Privatization's effects on R&D investments, in Calderini, M., Garrone, P., and Sobrero, M., eds., Corporate Governance, Market Structure and Innovation, Edward Elgar: Cheltenham.

NSF (1989). Science Resource Studies Highlights, National Science Foundation, NSF 88-311, March.

Nelson, R. A. (1984). Regulation, capital vintage, and technical change in the electric utility industry, *The Review of Economics and Statistics*, Vol. 66, No. 1, 59-69.

Nemoto, J. and Goto, M. (2004). Technological externalities and economies of vertical integration in the electric utility industry, *International Journal of Industrial Organization*, Vol. 22, 67-81.

Newbery, D. M. (2005). Electricity liberalization in Britain: The quest for a satisfactory wholesale market design, *The Energy Journal*, Volume 26, Special Issue, 43-70.

Newbery, D. M. (2002). Issues and options for restructuring electricity supply industries, Working Paper DAE 0210/CMI EP 01, Department of Applied Economics, University of Cambridge.

Newbery, D. M. G., Pollitt, M.G. (1997). Restructuring and privatisation of the CEGB - Was it worth it?, *Journal of Industrial Economics*, Vol.45, No.3, 269-304.

OECD (2000). Regulatory Reform in Network Industries, in OECD Economic Outlook No. 67, Organisation for Economic Co-Operation and Development, Paris.

OFGEM (2003). Developing Monopoly Price Controls, Update document, Consultation document, Office of Gas and Electricity Markets, February, London.

OFGEM (2004). Electricity Distribution Price Control Review – Regulatory Impact Assessment for Registered Power Zones and the Innovation Funding Incentive, Office of Gas and Electricity Markets, March, London.

Oulton, N. (1995). Supply side reform and UK economic growth: What happened to the miracle?, *National Institute Economic Review*, No.154, 53-70.

Perelman, S. (1995). R&D, Technological progress and efficiency change in industrial activities, *The Review of Income and Wealth*, Series 41, No. 3, September, 349-366.

Pint, E. (1991). Nationalisation vs. regulation of monopolies, *Journal of Public Economics* Vol. 44, 131-164.

Pollitt, M. G. (2002). The declining role of the state in infrastructure investments in the UK, in Pollitt, M.G., Tsuji, M., Berg, S. V. and M. G. Pollitt, eds, (2002), Private Initiatives in Infrastructure: Priorities, Incentives and Performance, Edward Elgar: Aldershot.

Rose, N. L. and Joskow, P. L. (1990). The diffusion of new technologies: Evidence form the electric utility industry, *The RAND Journal of Economics*, Vol. 21, No. 3 (Autumn) 354-373.

Sanyal, P. and Cohen, L. R. (2004). Deregulation, restructuring and changing R&D paradigms in the US electric utility industry, Department of Economics & IBS, mimeo, Brandeis University.

Scherer, F. M. and Ross, D. (1990). Industrial Market Structure and Economic Performance, 3rd Edition, Houghton Mifflin Company: Dallas.

Schneider, V. and Jäger, A. (2003). The privatization of infrastructures in the theory of the state: An empirical overview and a discussion of competing theoretical explanations, in Wubben, E. F. M. and W. Hulsink, eds., On Creating Competition and Strategic Restructuring: Regulatory Reform in Public Utilities, Edward Elgar: Cheltenham.

Schumpeter, J. A. (1942). Capitalism, Socialism, and Democracy, Harper and Row, New York.

Schumpeter, J. A. (1934). The Theory of Economic Development: An Inquiry into Profits, Capital, Credit, Interest, and the Business Cycle, Harvard University Press: Cambridge, Mass.

Shen, J.-C., and Reuer, J. J. (2004). Acquisition of entrepreneurial firms: How private and public targets differ, in: Pablo, A. L. and Javidan, M., eds., Mergers and Acquisitions: Creating Integrative Knowledge, Blackwell: Oxford.

Smith, V. K. (1974). The implications of regulation for induced technical change, *The Bell Journal of Economics and Management Science*, Vol. 5, No. 2, Autumn, 623-632.

Stoneman, P., ed. (1995). Handbook of the Economics of Innovation and Technological Change, Blackwell: Oxford UK.

Surrey, J., ed. (1996). The British Electricity Experiment – Privatization: The Record, the Issues, the Lessons, Earthscan: London

Sweeney, G. (1981). Adoption of cost-saving innovations by a regulated firm, *The American Economic Review*, Vol. 71, No. 3, June, 437-447.

Teece, D. J., ed. (1977). R&D in Energy: Implications of Petroleum Industry Reorganization, Proceeding of a Conference held at Stanford University, September 20-21, 1976, Institute for Energy Studies: Stanford University, August.

Thirtle, C. G. and Ruttan, V. W. (1987). The Role of Demand and Supply in the Generation and Diffusion of Technical Change, Harwood Academic Publishers: London.

USHR (1998). Electric Utility Deregulation: Implications for Research and Development, U.S. House of Representatives, Committee on Science, Subcommittee on Energy and Environment, 31 March 1998, Washington, D.C.

Westfield, F. M. (1971). Innovation and monopoly regulation, in Capron, W. M., ed., Technological Change in Regulated Industries, The Brookings Institution: Washington, D.C.

Wilder, R. P. and Stansell, S. R. (1974). Determinants of research and development activity by electric utilities, *The Bell Journal Economics and Management Science*, Vol. 5, Issue 2, 646-650.

Williamson, O. E. (1983). Markets and Hierarchies: A Study in the Economics of Internal Organization, Prentice Hall.

Wright, T.P. (1936). Factors affecting the costs of airplanes, *Journal of the Aeronautical Science* 3 122-128.

Appendix 1: Expanded Summary Tables

Table A3: Expanded summary - innovation and restructuring

	Restructuring aspect		
Innovation Measure	**Firm Size**	**Vertical Integration**	**Competition & Uncertainty**
R&D Spending	Multi-industry: - Likelihood and proportion of R&D spending within industries increases with size (Cohen & Kleppper, 96). Electric utilities: - R&D spending positively correlated (with size (Wilder & Stansell, 74; Delaney & Honeycutt, 76; Mayo & Flynn, 1988; Sanyal & Cohen, 04). - Internal and external R&D increase with firm size (Cohen & Sanyal, 04).	Petroleum: - Vertical integration has positive effect on basic, applied, and development research spending (Armour & Teece, 80).	Electric utilities: - Restructuring & competition reduces overall R&D spending and favours short-term research to long-term and/or collaborative research (Defeuilley & Furtado, 00). - Uncertainty has sig. neg. effect on utility R&D spending (Sanyal & Cohen, 04). - Wholesale power market has pos. (not sign.) effect on R&D spending. Share of customers eligible for switching supplier has sign. pos. effect. Share of customers switching has (insig.) neg. effect on R&D (Sanyal & Cohen, 04). - Uncertainty associated w. reform has negative effect on internal R&D, while arrival of actual competition has pos. sign. effect. External R&D increases w. uncertainty but declines w. arrival of competition (Cohen & Sanyal, 04). - Percentage of customers switching supplier has sign. neg. effect on internal and external R&D spending. Share of customers eligible for switching has sign. pos. effect on external R&D.
R&D Intensity		Multi-industry: - R&D intensity has pos. effect on vertical integration (Levy, 85).	
R&D Spending Complementarity / Trade-Offs			Multi-industry (incl. electric equipment): - Government R&D has positive effect on firms R&D spending (Mansfield & Switzer, 84; Becker & Pain, 03). Electric utilities: - Internal R&D has positive significant effect on external R&D spending (Cohen & Sanyal, 04). - Reorientation of innovation from technology solutions to customer-oriented products and organisational innovations (Markard et al., 04).
Innovation Output	Multi-industry: - Patents per R&D spending decreases w. size. But, return on R&D spending increases w. size due to cost spreading (Cohen & Klepper, 96).		Telecoms: - Anticipation of and actual competition reduces publications and increases patenting (Calderini & Garrone, 03a). Electricity equipment suppliers: - The slight increase in patents by electric utilities is considerably lower than increase in patents by of equipment suppliers (Jacquire-Roux & Bourgeois, 02).
Technology Adoption	Electric utilities: - Likelihood of new technology adoption increases w. firm size (Rose & Joskow, 90).		

Table A4: Expanded summary - innovation and ownership

		Ownership Aspect		
		Privatisation & Private Ownership	**Mergers & Acquisitions**	**Leverage, Investment, Dividend, etc.**
Innovation Measure	**R&D Spending**	Multi-industry: - Privatisation (dummy) has significant positive effect on R&D spending. Private share in company has significant negative effect on R&D spending (Munari & Sobrero, 03b). Privatised regulated monopoly: - Negative significant effect on R&D spending (Munari & Sobrero, 03b; Munari et al., 02).	Multi-industry: - Mergers have negative effect on R&D spending (NSF, 89). Survey: - M&As among similar firms leads to neutral / negative effect on innovation input (Calderini & Garrone, 03b). - Merger among technologically substitutive firms has significant negative effect on R&D spending. Merger among technologically complementary firms has positive (not significant) effect on R&D spending (Calderini et al, 03). Electric utilities: - Pending merger has significant negative effect on probability of engaging in R&D (Sanyal & Cohen, 04).	Multi-industry: - Leverage has significant positive effect on R&D spending (Munari & Sobrero, 03b). - Investments and R&D spending are mutually (significantly) negatively correlated. Dividends and R&D spending are mutually negatively correlated. Balance of cash positively correlated w. R&D spending (Gugler, 03). - Leverage (as opposed to acquisitions) has significant negative effect on R&D spending (Hall, 90)
Innovation Measure	**R&D Intensity**	Multi-industry: - Privatisation (dummy) has significant positive effect on R&D intensity. Private share in company (dummy) has significant negative effect on R&D spending (Munari & Sobrero, 03b).	Survey: - The increased leverage effect of M&As has negative impact on R&D intensity (Calderine & Garrone, 03b). Multi-industry: - Acquisitions result in reduced R&D intensity (Hitt, et al., 91). - Spatial dispersion in acquisitions has negative effect on R&D intensity (Shen & Reuer, 04).	
Innovation Measure	**R&D Activity**	Multi industry: - Privatisation results in shift of focus toward applied and commercial research and restructuring of collaborative research (Munari et al., 02).		
Innovation Measure	**Patenting Activity**	Multi-industry: - Privatisation and private share in firm positively correlated w. patenting activity (Munari & Sobrero, 03b). - Privatisation increases patents per researcher (Munari, 03).	Multi-industry: - Decline in patenting activity after horizontally /technology unrelated acquisitions (Calderini et al, 03). - Acquisitions result in reduced patent intensity (Hitt, et al., 91). - M&As among similar firms leads to positive/neutral effect on R&D output. M&As among diverse firms has positive effect on R&D output (Calderini & Garrone, 03b).	Multi-industry: - Number of patents applied for is positively correlated w. R&D spending (Gugler, 03).
Innovation Measure	**Adoption of New Technology**	Electric utilities: - Private utilities more likely to adopt new technologies (Rose & Joskow, 90)		

Table A5: Expanded summary - innovation and regulation

		Regulation Aspect		
		ROR regulation	**State vs. Local Regulation**	**Regulatory lag & Incentive Regulation**
Innovation Measure	**R&D Spending**	Electric utilities: - Targeted technology policies more effective than ROR in promoting R&D (Nelson, 84). - Allowing R&D in rate base Dummy) has a significant effect on R&D spending (Mayo & Flynn, 88).	Electric utilities: - State vs. local regulation (dummy) not significant for R&D spending (Wilder & Stansell, 74; Delaney & Honeycutt, 76).	Electric utilities: - Incentive regulation has significant negative effect on internal and external R&D spending (Cohen & Sanyal, 04).
	Innovative Activity			Model: - Level of innovative activity increases w. length of regulatory lag (Bailey, 74). - Regulated firm may delay or choose timing of adoption of innovation to increase profit across regulatory lag (Sweeney, 81).
	Adoption of New Technology	Model: ROR leads to adoption of labour augmenting technologies and under-investment in capital augmenting technologies (Smith, 74). Electric utilities: - ROR leads to adoption of labour augmenting technologies and under-investment in capital augmenting technologies (Frank, 03). Gas pipelines: - ROR results in adoption of non-capital augmenting technologies (Granderson, 99).		
	Technical Change	Electric utilities: - Small effect from allowed ROR on technical change (Nelson, 84).	Electric Utilities: - ROR results in lower rate of technical change than under deregulation and loose local regulation (Frank, 03; Granderson, 99).	Model: - Rate of innovation under ceiling price higher than under ROR (Magat, 76).