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Electricity Policy Research Group

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EPRG Working Paper 0901

Cambridge Working Paper in Economics 0902

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Keywords Electricity, patent, innovation, technology, liberalisation

JEL Classification L94, O31, Q32, Q38

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Publication January 2009
Financial Support ESRC

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12 January 2009

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1. Introduction

The liberalization trend of electricity sectors around the world which began in the early 1990s has transformed the organization and operating environment of the electricity supply industry. In general, liberalization has achieved some improvement in the technical efficiency of the industry. However, in the long run, the main source of continued efficiency improvement of the sector is through technical change and innovation.

At the same time, evidence suggests that liberalization has, at least, partially contributed to a decline in research and development (R&D) as the main input in innovative activities. A survey of the industrial literature in Jamasb and Pollitt (2008) suggests that most aspects of electricity reform theoretically and empirically have had a negative effect on R&D in the sector. The ESI has a rather low R&D intensity relative to most other industries. Hence a lasting decline in innovative activities of the sector is a cause for concern. However, the effect of liberalization on the output of innovative activities such as R&D and patenting is significantly less well understood.

Basberg (1987) reviews the literature on patents and technical change. The paper classifies the literature on patents into three categories – i.e. those concerning the legislation and functioning of the patent system, those studying the rationale of the system, and those using patents as technical information. The latter category is in turn divided into three types: (i) the studies of patents and technological changes measured by patents and economic development, (ii) those addressing diffusion of technology across countries, and (iii) those analyzing the process of innovation and the relationship between R&D, patents, and productivity. The emergence of liberalization and privatization of a range of infrastructure and network industries around the world since the early 1990s has given rise to the need for new types of studies such as Hattori (2007), and Johnstone et al. (2008), and Jamasb and Pollitt (2008) that examine the effect of reforms and policies on R&D, patents, and innovation in these sectors.

This study focuses on the case of the electricity sector in the UK employing an output perspective of measuring innovative activity - i.e. by examining the patenting activity of the sector. The UK was a pioneering country in implementing an extensive electricity sector liberalization program making it a suitable case for a detailed study of patenting activities. Studying the patenting activity related to the sector can shed some light on the changes in innovative activities in the sector following its liberalization.

Section 2 presents a review of the relevant studies on the relationship between liberalisation, innovation, and patenting in the electricity sector. Section 3 describes our methodology of studying the patents to study innovation in the sector. Section 4 presents the results of patent counts of the major actors in the UK electricity sector before and after liberalisation. Section 5 presents the results of patenting activities at the sector level and for two specific renewable technologies. Section 6 discusses some aspects of developing a suitable framework for energy technologies innovation system in the post-liberalisation electricity sector and Section 7 concludes.

2. Electricity Sector Liberalisation, Innovation, and Patents

2.1 Liberalisation and innovation

The rate of return on research and development (R&D) investments as the main driver of patents has been found to be persistently high, with estimates of the social rate of return around 50% and the private return around 20-30% (Margolis and Kammen, 1999). However, in many cases the risks involved and lack of appropriation can result in market failure and underinvestment in private R&D that would have high social return. R&D investments are inherently risky endeavors and firms expect high returns from them. Also, uncertainty in appropriating the full benefits of R&D implies that the private sector is likely to underinvest in R&D. Market failure in the provision of R&D as a public good is the main rationale for the government to play a role in its promotion. This role can be, for example, in the form of government support for R&D activities, or through policies aimed at creating incentives for the private sector to invest. (Margolis and Kammen, 1999).

The literature is generally positive about the effects of liberalisation on the technical and commercial performance of the sector. Nonetheless, some studies have raised concerns regarding the long-term effects of liberalization on energy R&D (see GAO, 1996; Dooley, 1997; Bell and Seden, 1998; Bell and Schneider, 1999). Jamasb and Pollitt (2008) survey the industrial organization literature on innovation and conclude that many aspects of electricity sector liberalisation have a negative effect on energy R&D investments and innovation in the sector. Our earlier paper discusses how liberalisation has led to a decline in R&D expenditures of electric utilities and to a shift towards short-term customer-oriented R&D projects at the expense of long-term R&D projects that entail public benefits but cannot be appropriated by the utilities. We also stress the role of government support to bridge the gap of insufficient private R&D expenditures.

Hattori (2007) examines the effect of electricity sector liberalization on energy technology patents in Japan. The study finds that since the mid-1990s there has been a decline in the number of patents. At the same time, the number of claims for patents as well as claims per patent has increased indicating a stronger tendency towards commercialization and securing the rights to new ideas. Calderini and Garrone (2003) find a somewhat similar indication of the effect of liberalisation on innovation in the telecommunications industry. They econometrically examined innovation for 17 former European monopolists using patents as a proxy for applied research output and scientific publications as a proxy for basic research output. The results suggest “institutional discontinuity” which is biased towards short-termisim in that the incumbents increased their patenting activity while they reduced their publication activity following liberalisation. The findings indicate that competitive pressure can lead to ‘short-termism’ which comes at the expense of the long-term benefits of basic research.

Johnstone et al. (2008) examine patent applications in a number of renewable energy technologies in OECD countries. The analysis shows that renewable policies can have a significant effect on the number of patent applications for some types of technologies. Some policy instruments such as taxes, tradable certificates, and obligations appear to be more effective than others.

Jacquier-Roux and Bourgeois (2002) postulate an increasing role for the upstream heavy electrical equipment industry relative to the electricity supply industry in terms of patents**.** They examine the number of patents granted to fifteen world groups engaged in electricity production and heavy electrical equipment industry over the period 1985-1998. The findings indicate that: (i) the dynamics of the networks of technological creation are characterised by a movement upstream of the network from asset operators (generating and grid companies) towards technology suppliers, and (ii) that networks of competitive advantages and bargaining power creation continue to be based on the asset operators and their strategies. The results underpin the importance of including upstream sectors in the analysis of the sector.

Using patents as a metric for innovation, Sanyal and Ghosh (2008) find that for both the equipment manufacturers and the particular electric equipment patent classes, the amount of innovation declined after the 1992 Energy Policy Act, which started the deregulation process in the US power industry. Thus, competition in the downstream generation sector adversely affected the innovation behavior of electric equipment manufacturers. They identify two channels through which the effects on innovation are transmitted: the appropriation effect which decreases innovation after deregulation, and the competition effect, that increases innovation when entry restrictions are removed. They find that the appropriation effect dominates the competition effect, reducing the overall quantity of innovation. In addition, "quality," as it is measured by citations, has been adversely affected, and innovation has also become more "specific" since restructuring (Sanyal and Ghosh, 2008, pp.6).

Markard and Truffer (2006) analyze how liberalisation has altered the innovation processes in the electricity sector focusing on radical innovation in four generation technologies - nuclear power, combined cycle gas turbines, wind power, and fuel cells. They observe that, traditionally, the development of the sector has been strongly path-dependent and, as a result, innovation has been more of an incremental rather than of a radical nature. Existing technological regimes tend to be predominant, and well-established firms oppose radical innovations as these might endanger their market position and imperil their long-term investments. However, liberalisation alters the structure and operating environment of the sector (e.g. Joskow, 1998; Sioshansi, 2001) and the new market conditions are likely to change the forms of resistance towards radical innovations. Markard and Truffer (2006) find that at the firm level, liberalisation induces a shift from incremental, technology-oriented innovation to more radical, customer-oriented product and organisational innovations.

At the sector level, liberalisation can be a driver for the overall level of innovation activity as competition represents a significant challenge for incumbent utilities and potential entrants. This is in line with the predominance of 'Darwinian effects' over 'Schumpeterian effects' resulting in a positive relationship between competition and R&D (see Calderini and Garrone, 2003). The Markand and Truffer study postulates that the "widespread and coordinated resistance of established utility companies against radical innovations, which was characteristic under monopoly conditions, gives way to more diversified strategic responses" (p. 623).

2.2 Innovation analysis using patent data

A number of studies have used patent analysis to study innovation trends in the energy sector. These studies provide helpful insights on how patent data can be a useful instrument in studying innovation and the factors that influence the way it transpires. They vary in scope and breadth with some focusing on specific sectors or sub-sectors and some focusing on companies that share common characteristics (e.g. belong to the same sector or that have similar size or market power). Some patent studies use time series data, some use cross sections, while others employ panel data analysis.

Constructing suitable datasets for the study of patents at sector level is not straightforward. Most empirical studies utilizing patent data require structured searches in the patent databases in order to construct meaningful datasets. This is partly due to the system by which publicly available patents are classified. Patent classifications are generally based on the technical features of patents rather than being attributed to the industry of origin (to which the patentee company belongs) or the industry benefiting from the patent. Therefore, "*the resulting classification system is … only rarely related to economists' notions of products or well-defined industries*" (Griliches, 1990, p. 1666).

Depending on the level of aggregation and the subject matter in question, various studies follow different approaches - generally involving some degree of compromise - in attempting to overcome the above mentioned difficulty while searching databases. The fact that many studies focus on specific companies partly reflects the need for a compromise in order to be able to frame the analysis.[1]

As mentioned previously, a study of patents of electric utilities alone will not give a full picture of innovation in the industry. Rather in order to study technological creation it is better to include the range of relevant actors in that industry. In the case of the electricity sector this may be done in two approaches. The first approach is to identify initially major electric utilities, equipment suppliers, and major research institutes and analyse the patents granted to them over a given period. For example, Jacquier-Roux and Bourgeois (2002)

[1] For example, Bergek and Berggren (2004) analyse patent data to study R&D internationalisation of two multinational firms in the electro-technical industry (GE and ABB). Given that the interest here was the electro-technical industry and that GE's operations in particular are active in other industries, searching by company name would not be sufficient and thus defining the electro-technical technology field was a necessary first step. To do so, they only consider patent classes in which ABB was active as an approximation, since in contrast to GE, ABB's activities were largely confined to the electro-technical industry.

examine the patents granted to the first fifteen world groups engaged in electricity production and heavy electrical equipment industry over the period 1985-1998. Electric technology was defined by an agglomeration of 30 different patent classes.[2]

In the second approach, patent studies identify the range of technologies that are of interest and specify corresponding keywords that are likely to appear in the abstract of patent documents relevant to each technology. They can then conduct a keyword based search of patent databases. The advantage of this approach is that one can retrieve patents granted to major as well as minor players. This approach is followed by Margolis and Kammen (1999), Nemet and Kammen (2007), and Lanjouw and Mody (1996), however it has some limitations. For example, there can be limits to the number of key words that may be used. Also, it is possible that not all of the relevant patents may be picked up by the key words or that irrelevant patents may be in the dataset (Nemet and Kammen, 2007).

Evidence suggests that there is a direct relationship between R&D and scientific publications on the one hand and patenting activity on the other. For example, Margolis and Kammen (1999) use data on R&D investments and patent records to examine the relationship between expenditures on R&D and innovation in general and with a particular focus on the energy sector. They search energy technology patent titles in the US Patent and Trademark Office (PTO) bibliographic database (PTO, 1998) using keywords.[3] Also, patent abstracts of two energy technology sub-sectors were searched using key words. The study indicates that "*for the US economy as a whole and for the energy sector specifically, R&D investments and patents were highly correlated between 1976 and 1996. This supports the hypothesis that the US under-invests in energy-related R&D. Further, it illustrates that cutbacks in energy-related R&D have dramatic impacts on innovation in the energy sector*" (p. 579). Also, Narin et al. (1997) find increasing linkage between academic scientific publications and patenting activity in the US.

Taylor (2001) describes two approaches to create patent datasets to study the influence of government intervention on innovation. In the first approach, patents are identified through a search of patent subclasses. A patent examiner was interviewed in order to identify the US PTO subclasses relevant to the technology of interest (here SO_2 control technologies).

[2] These include the following IPC classes: E02B, F01D, F02B, F02C, F03B, F03D, F22B, F23, F24 J, F28, G2C¸ H01M, HO2K, E02D, F01K, F01P, F02D, F02G, F02K, F04, F22D, F22G, G21B, G21D, G21F, G21H, HO2N, HO2P, G05, HO5K.

[3] The key words used were (oil or natural gas or coal or photovoltaic or hydroelectric or hydropower or nuclear or geothermal or solar or wind) and (electric* or energy or power or generat* or turbine) (p. 578).

These were supplemented with a couple of other subclasses (fuel treatment subclasses relevant to pre-combustion removal technologies) and a search of all US PTO patents was conducted. The patent documentations retrieved could ideally be further filtered by reading all the documents and excluding any irrelevant patents. However, this is a highly labour-intensive task and was not carried out. In the second approach, patents were identified through an electronic keyword-based search of patent abstracts and the manual assignation of captured patents into technological and organisational categories.

The effectiveness of the two approaches in identifying relevant patents was evaluated by comparing the percentages of commercially validated patents that they identified. In that respect, the abstract-based and supplemental datasets proved to be more effective. Subsequently, irrelevant patents were discarded. The resulting dataset was analysed both through simple models based on government actions and through expert elicitation. Both types of analyses concluded that the existence of government actions positively, although temporarily, affected SO_2-related patenting activity. It is noteworthy that the technology of interest in this case is rather specific and a keyword-based search of patent abstracts is likely to capture a significant number of relevant results.

Nemet and Kammen (2007) examine R&D investment and US PTO patent data to develop indicators of innovative activity and assess the feasibility of expanding R&D in five emerging energy technologies (wind, PV, fuel cells, and nuclear fusion and nuclear fission). They use the two approaches followed in Taylor (2001) and described in Nemet (2007) - i.e. using patent classes defined by the US PTO and using keywords to search the text of patent abstracts. The first step was to interview the patent examiner responsible for a given technology, for instance wind power, since the person is familiar with searching using both relevant classes and keywords. The patent examiner indicated two classes where most wind energy patents were most likely to come out, two more classes that might have also included some wind energy patents and also suggested several keywords for finding patents outside the usual classes.

Keywords were then used to search the patent abstracts in the US PTO Bibliographic Database to identify those relevant to wind power. This involved devising a Boolean search string that maximises the number of relevant and minimises the number of irrelevant patent hits. Building the search string was an iterative process that balanced errors of inclusion with errors of omission. Three reference points were used in constructing the search string: (i) the set of keywords for wind power defined by Margolis and Kammen (1999) for a similar purpose, (ii) the keywords recommended by the patent examiner (iii), the set of patents in classes where wind power related patents are most likely to appear, as they were identified by the examiner. The search string was iteratively adjusted so that it included nearly all patents in these two classes, while minimising irrelevant patents.

Finally, the set of patents retrieved by the abstract-based search was manually read and any patents not relevant to wind power were discarded. Using multiple measures of patenting activity, they show a widespread decline in innovative activity that is correlated with R&D investment - notably in wind and solar power. Trends in venture capital investment and fuel cell innovation are two promising cases that run counter to the overall trends in the sector. Finally, drawing on work of others on optimal level of energy R&D, Nemet and Kammen state that a five to ten fold increase in energy R&D investment is warranted and feasible.

3. Methodology - Using Patents to Study Innovation in the UK

As discussed in the previous section, constructing datasets of patents for the electricity industry requires considerable rearranging of available data. This is in part due to the current system of patent classification. For instance, the European Patent Office (EPO) database has a designated major class of patents denoted "H: Electricity". At first sight it might seem that all patents relevant to electricity sector innovations would be classified under this class. However, on closer examination it becomes apparent that this is not the case. Not only are some patents relevant to the electricity sector classified under other major classes, but also Class H includes patents that are entirely irrelevant to the electricity supply sector. Figure 1 presents an overview of the main subclasses of Class H.

Class H would include most appliances that utilise electricity. For example, subclass H02J7 "Circuit arrangements for charging or depolarising batteries or for supplying loads from batteries" would also include patents related to mobile phone chargers, irrespective of whether these have been filed to claim the ability of a charger to reduce electricity consumption. Another example of a group of patents irrelevant to the electricity sector is subclass H05C "Electric Circuits or Apparatus Specially Designed for Use in Equipment for Killing, Stunning, or Guiding Living Beings". Even if irrelevant subclasses could be identified and eliminated however, the existence of subclasses of other major classes that include patents relevant to the electricity sector poses difficulties.

Table 1 gives examples of some of the subclasses under other major classes in the EPO database that include patents relevant to the electricity sector. For instance, a considerable number of wind and wave energy patents are classified under class “F: Mechanical Engineering” and more specifically under subclass “F03: Machines or engines for liquids”. Although on some occasions the same document is also classified under a subclass of Class H (the system allows for multiple classifications), this is often not the case. Another example is subclass “G21: Nuclear physics; nuclear engineering” where virtually all patents related to nuclear power are to be found.

The approach of this study

Broadly speaking, there are two alternative approaches to study the patents that are relevant for the electricity sector before and after liberalization. The first is an “actor-based” approach by searching the patents associated with specific major companies, utilities, and other organizations. The second is a “keyword-based” search which can be used for sector level as well as for technology level analysis.

The former approach can be used to examine the patents originating from within the electricity supply industry while the latter approach is concerned with patents where the electricity sector is the main user. A certain degree of overlapping between the two approaches can be expected. In this study we utilize both the actor-based and the keyword-based search of the electricity technology patent information.

Company-based search - This approach retrieves patents filed by downstream players (e.g. Central Electricity Generating Board and its successors, Regional Electricity Companies RECs) and other major players conducting research (Electricity Council, EA Technology, UK Atomic Energy Authority). The results from this approach are presented in Section 4.

Keyword-based searches – This approach aims to give a picture of innovative activity at the sector level. Given the limited number of keywords accepted by the database search engine (four), we use relatively general terms in a Boolean search string. This permitted a low level of granularity that reflects the desire to cover overall trends in innovation activity of the sector and therefore include as many technologies and as many players as possible. This approach is presented in Section 5. We also use a keyword-based search to examine innovative activity concerning two specific technologies wind power and photovoltaics). We devised Boolean search strings which have a higher level of granularity using technology specific terms. This approach is also described in Section 5.

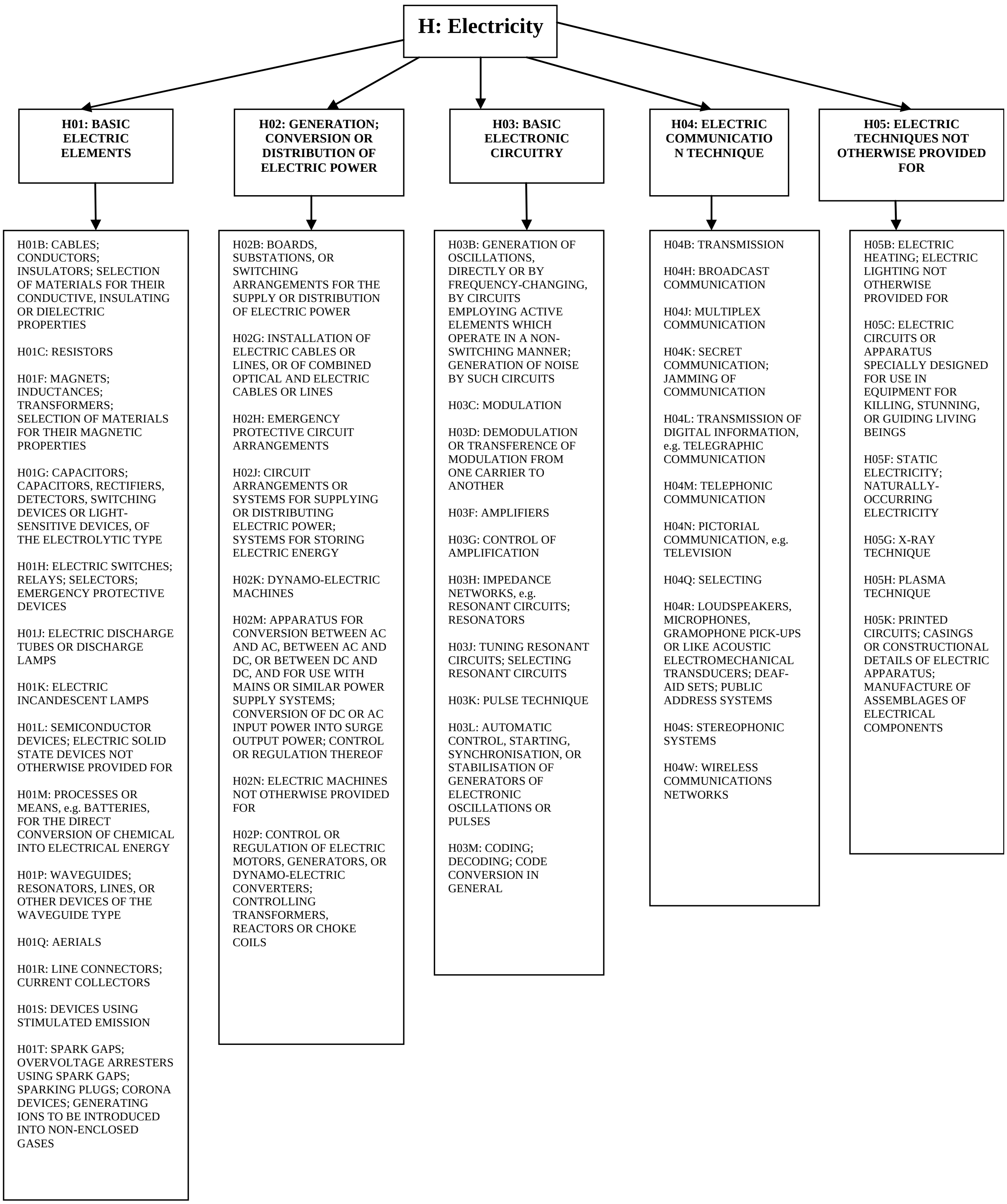


Figure 1: Class H "Electricity" and its subclasses
Source: esp@cenet, European Patent Office (http://ep.espacenet.com)

<table>
<tr><th>CLASS</th><th colspan="2">SUBCLASS</th></tr>
<tr><td rowspan="4">F: Mechanical engineering; lighting; heating; weapons; blasting engines or pumps</td><td colspan="2">F02: Combustion engines; hot-gas or combustion-product engine plants</td></tr>
<tr><td colspan="2">F03: Machines or engines for liquids; wind, spring weight and miscellaneous motors; producing mechanical power; or a reactive propulsive thrust, not otherwise provided for</td></tr>
<tr><td colspan="2">F17: Storing or distributing gases or liquids</td></tr>
<tr><td colspan="2">F23: Combustion apparatus; combustion processes</td></tr>
<tr><td>B: Performing operations; transporting</td><td colspan="2">B60M: Power supply lines, and devices along rails, for electrically-propelled vehicles</td></tr>
<tr><td rowspan="2">E: Fixed constructions</td><td rowspan="2">E02B: Hydraulic Engineering</td><td>E02B9: Water-power plants; Lay-out, construction or equipment, methods of, or apparatus for, making</td></tr>
<tr><td>E02B7: Barrages or weirs; Lay-out, construction, methods of, or devices for, making</td></tr>
<tr><td>C: Chemistry and Metallurgy</td><td colspan="2">C01B3: Hydrogen; gaseous mixtures containing hydrogen; separation of hydrogen from mixtures containing it; purification of hydrogen</td></tr>
<tr><td></td><td colspan="2">C10K3: Modifying the chemical composition of combustible gases containing carbon monoxide to produce an improved fuel, e.g. one of different calorific value, which may be free from carbon monoxide</td></tr>
<tr><td rowspan="3">G: Physics</td><td colspan="2">G21: Nuclear physics; nuclear engineering (fusion reactors, nuclear reactors, nuclear power plant, protection against radiation, treating radioactive contaminated material, decontamination arrangements, conversion of chemical elements, radioactive sources, obtaining energy from radioactive sources….)</td></tr>
<tr><td colspan="2">G01R: Measuring Electric Variables; Measuring Magnetic Variables (e.g. Instruments capable of converting two or more currents or voltages into a single mechanical displacement; Arrangements for measuring electric power or power factor)</td></tr>
<tr><td colspan="2">G07F15: Coin-feed apparatus with meter-controlled dispensing of liquid, gas or electricity</td></tr>
</table>

Table 1: Examples of patent subclasses relevant to electricity sector not included in Class H

Source: esp@cenet European Patent Office (http://ep.espacenet.com)

4. Patent Activity by Major Actors

In the years preceding liberalization government R&D in the energy sector had begun to decrease. In particular, the single largest spending on R&D was on nuclear power technology which from the 1940s to 1970s had links to military applications.[4] However, from the mid-1980s, nuclear R&D spending began to decline as a result of cutbacks in costly research projects. Figure 2 shows total government energy R&D spending and the share of total spending on nuclear.

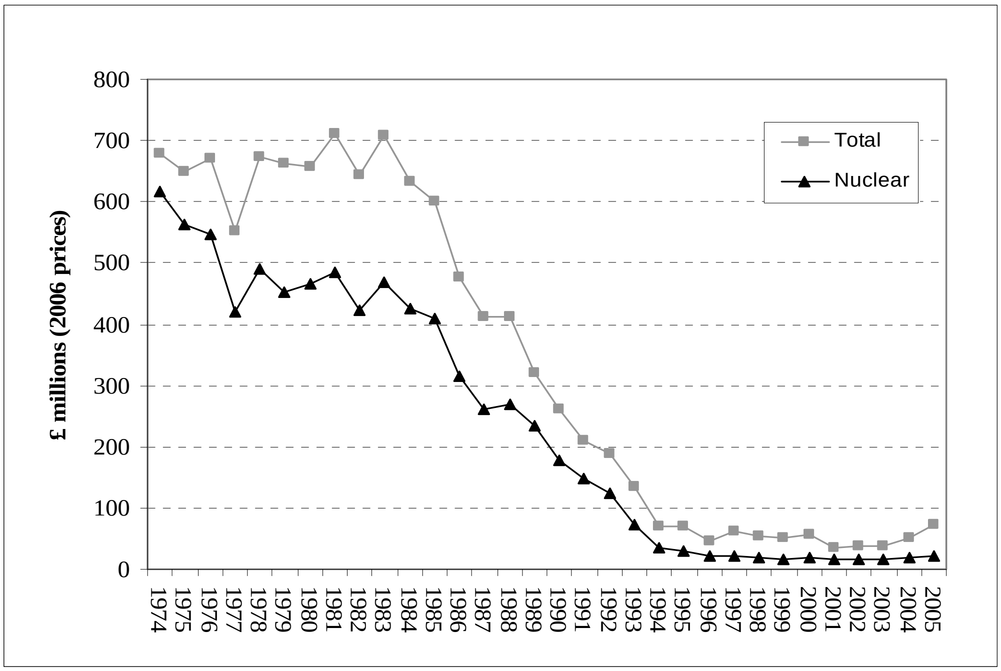


Figure 2: Government energy R&D in the UK: Total and nuclear R&D spending
Source: IEA Energy R&D statistics database

Nuclear power was however not the only area to face a decline in R&D spending over this period. The decline in other areas such as energy efficiency is also evident. As can be seen in Figure 2 the decline in total government spending on R&D began in the mid-1980s, prior to liberalization. Figure 3 shows that this decline was broad based and included spending reduction in all major categories. In recent years, against the backdrop of security of supply and climate change policy targets, the spending level shows signs of revival in particular on renewable energy although the increase is from a low base (Figure 4).

[4] The public R&D figures are likely to be exclusive of R&D spending on military applications. In addition, the outcomes of defence related R&D would not lend themselves to patenting.

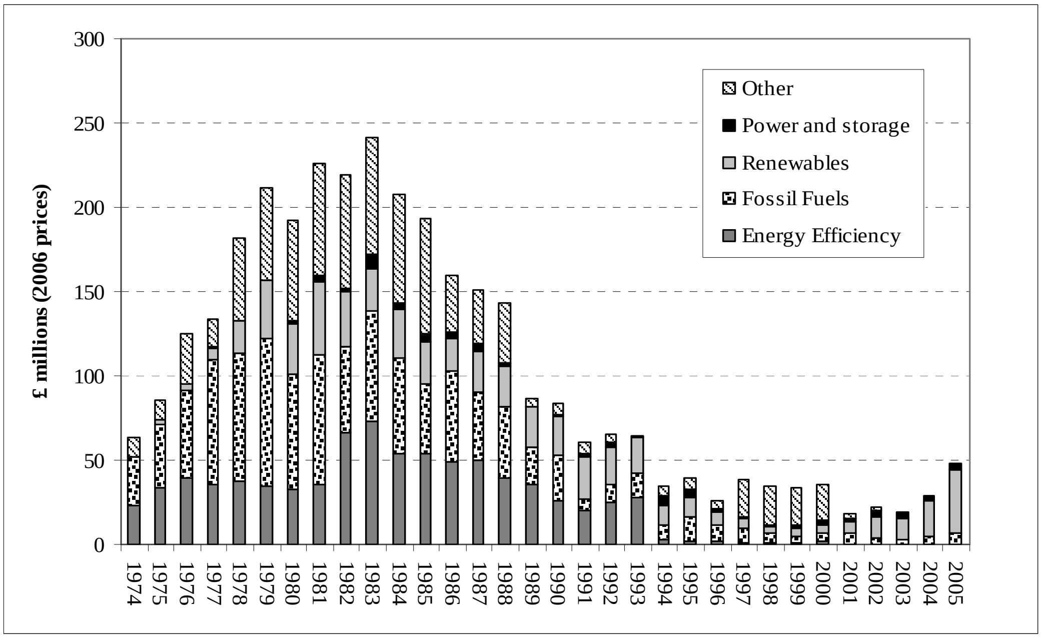


Figure 3: Government energy R&D in the UK - Main categories (excluding nuclear)
Source: IEA Energy R&D statistics database

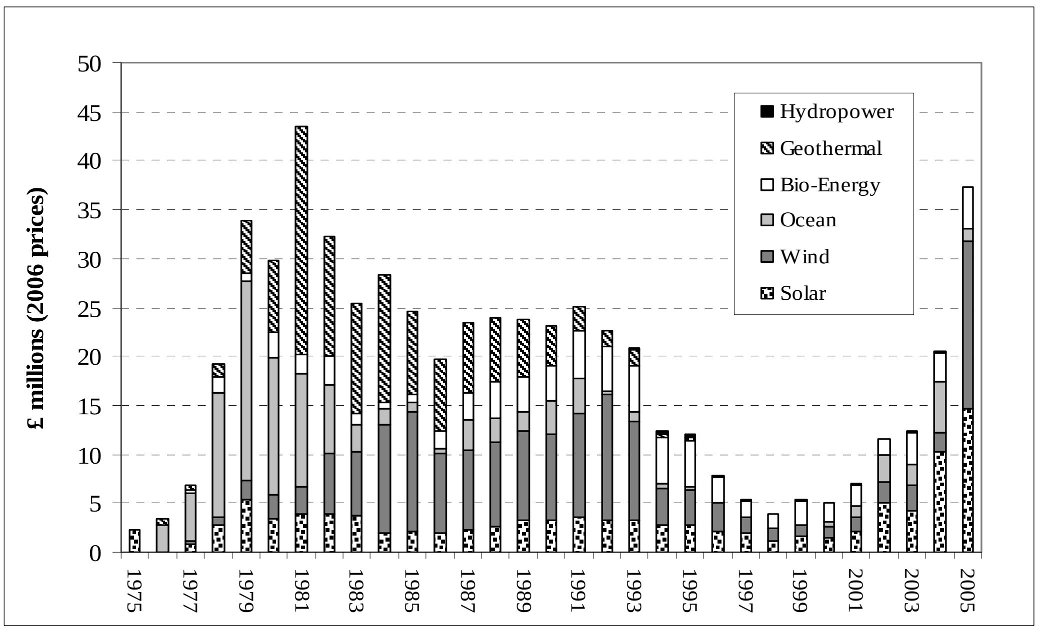
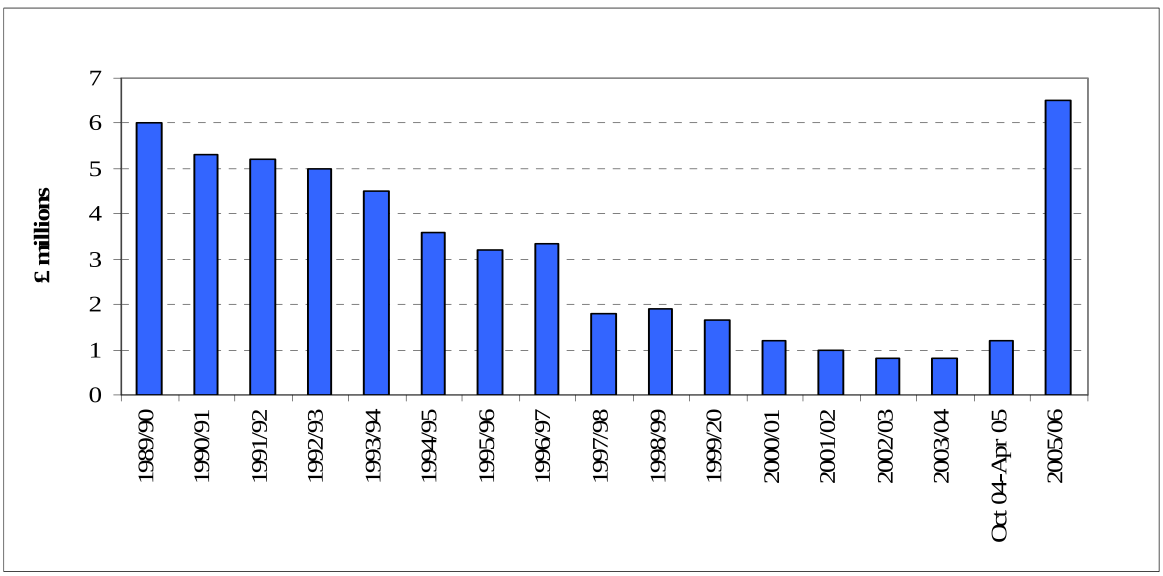


Figure 4: UK government R&D spending - renewable energy
Source: IEA Energy R&D statistics database

There is only limited data on the R&D spending of privatized electricity companies in the aftermath of liberalization. This is partly due to the lack of a common definition of what constitutes R&D and partly because of potential commercial sensitivity of such data (Jamasb and Pollitt, 2008). It appears, however, that the new entrants to the competitive generation markets as Independent Power Producers (IPPs) hardly spend any notable amount on R&D. Evidence from electric utilities in the US and Japan indicates that their R&D spending declined in response to deregulation of the sector (see Sanyal and Cohen, 2004; Cohen and Sanyal, 2004; Jamasb and Pollitt, 2008).

The data on R&D spending of the distribution utilities shows a clear decline in R&D by the privatized utilities in this segment of the sector. It should be noted that distribution utilities are natural monopolies and have been subject to an incentive regulation regime following the liberalization of the sector. This means that private utilities are not likely to invest in R&D beyond what they would be allowed by the regulator (Jamasb and Pollitt, 2008). As a result, since 2005, the introduction of the Innovation Funding Incentive (IFI) which allows distribution (and subsequently transmission) utilities to spend up to 0.5% of their revenue on R&D has had a positive effect on spending levels by distribution utilities (Figure 5).



Notes: *Data from 1989/90 to 2003/04 is for collaborative spending on R&D amongst the DNOs through a single provider. For comparison, in 2003/04 the R&D spending of the DNOs was £2.1 (see Ofgem, 2004, p.160). **Data from October 2004 – April 2005 and 2005/06 shows reported total IFI spend.

Figure 5: R&D spending in the UK distribution utilities

Source: Ofgem (2007)

The UK 1990 electricity reform led to significant changes in the structure and ownership of the UK's electricity supply industry. Some of the changes were part of an intended restructuring while others were the consequence of adaptation to market competition and regulatory incentives. For example, prior to liberalization of the sector major countries such as the UK and France had a network of domestic equipment suppliers whose products and R&D were aimed at the national markets. After liberalization, private utilities preferred to purchase equipment in international markets. As a result, some suppliers eliminated duplication in their activities in countries such as the UK where their business based around national utilities had disappeared. This in turn increased incentives for consolidation among equipment manufacturers. Table 2 shows the main actors prior to and after the 1990 reform.

Prior to 1990 reform	**Post 1990 reform**
• Central Electricity Generating Board (CEGB) - The monopoly in charge of generation and transmission for England and Wales. • Distribution - Area Electricity Boards (AEBs) • South of Scotland Electricity Board • North of Scotland Hydro-Electric Board • Northern Ireland Electricity (NIE) • Electricity Council • UK Atomic Energy Authority (UKEA) • British Nuclear Fuels (BNFL)	• National Power • Power Gen • Nuclear Generators: Nuclear Electric, Scottish Nuclear, Magnox Electric, British Energy • National Grid • Scottish Power • Scottish Hydro Electric • Regional Electricity Companies (RECs) • EA Technology • UK Atomic Energy Authority (UKAEA) • British Nuclear Fuels (BNFL)

Table 2: Major Actors in the Electricity Supply Industry's R&D

The decline in R&D spending after privatisation and liberalisation has had a visible effect on patenting activities in the sector. As described in section 3, we firstly use an actor-based search of patents to identify this effect on the major companies and organisations in the sector. Figure 6 shows a broad picture of patenting activities in the UK electricity sector since 1958. The figure shows a marked decline in the overall patenting activity of the CEGB and its successors as well as by the Electricity Council, the Regional Electricity Companies (RECs) and their successors currently known as Distribution Network Operators (DNOs), AEA Technology, and the United Kingdom Atomic Energy Authority (UKAEA). As shown in Figure 6, the dominant position of nuclear R&D spending was also reflected in the high proportion of nuclear energy patents. The eventual decline in R&D also led to a marked reduction in these patents. It is noteworthy that the downward trend in R&D and patenting had already started before the 1990 privatization and liberalisation but continued afterwards.

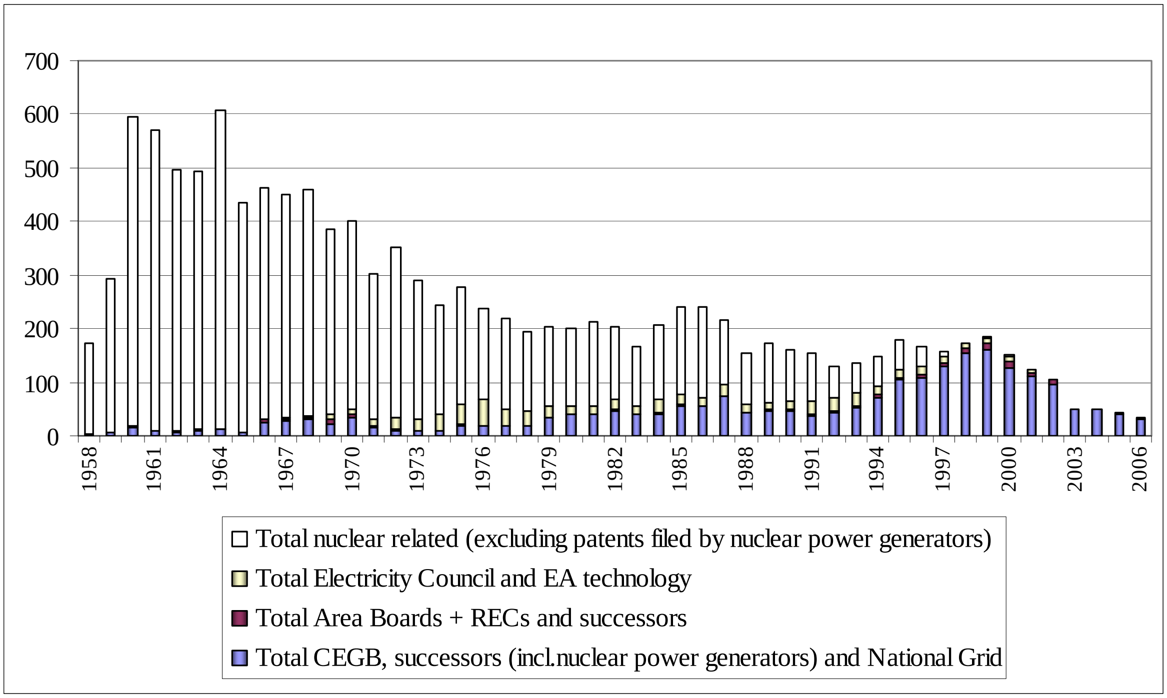


Figure 6: Patent count for the sector by major types of actors

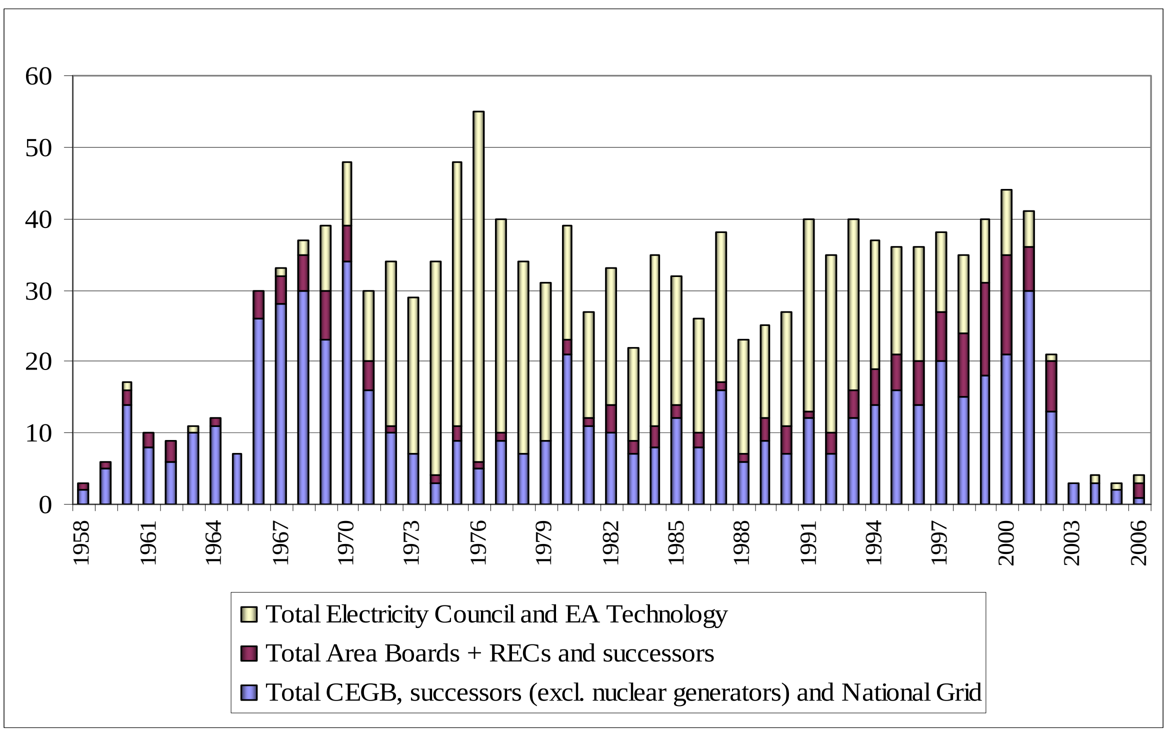


Figure 7: Patent count for the sector (excluding nuclear) by major types of actors

Following the reform the successors of the CEGB increased their patenting activity, although this also includes patents by nuclear generators and in particular BNFL as a major contributor.[5] As the case of nuclear may be regarded as somewhat special, Figure 7 focuses on the non-nuclear patenting activities of the sector. As shown from Figures 6 and 7, the patenting activity of the generating companies increases thus reversing the trend albeit to a limited extent. However, the downward trend returns around the year 2000. Regarding the distribution utilities, we find a low level of patenting activity after the reform while we hardly detect any such activity prior to the reform.

It appears, therefore, that post liberalisation there is some increase in the patenting activity by both generation (both nuclear and others) companies and distribution utilities, although there is a decreasing patenting activity by the Electricity Council and its successor, AEA Technology. Given the evidence of decline in government R&D spending and the common belief of the same in the utilities and perhaps also among the equipment manufacturers, this can indicate higher propensity to patenting as a result of competition and increased commercialisation of the sector.[6] However, as mentioned, a long-term decline in R&D as the main source of innovation should eventually lead to reduced patenting activity.

Figures 8 and 9 show the patenting activity by the main electricity generation companies. Following 2001, there is a significant decline in overall patenting activity by the major UK electricity sector actors; a trend which accelerates in the 2003-2006 period. As shown in Figure 8, BNFL accounts for most of the rise of patenting activities by nuclear generators after the reform and after the eventual decline from around 2000. Figure 9 shows that patenting activity by non-nuclear generators increased following the reform but began to decline from 2001-2002.

National Power inherited most of the CEGB's research facilities. During the 1990s, research activities of National Power were declining increased commercialisation of the sector meant that the company's patenting activities increased. At the same time, most of the remaining R&D of the National Power and PowerGen was directed at improving operating efficiency of plants. In 2001, National Power demerged into two separate

[5] Note: BNFL is classified as a nuclear power generator.

[6] It should be noted that patenting may be part of a wider strategy which also includes options such as keeping the research results secret or publishing the results in order to prevent ideas being patented in the future by competitors and/or reduce the cost of protecting the rights to the patents.

companies Innogy and International Power with the former being responsible for the UK operations. In 2002, Innogy was taken over by the German utility RWE and was renamed as RWE Npower plc. The takeover of National Power led to significant downsizing of research and patenting activities of the company such as the ending of fuel cell storage project Regenysis. As a result, after 2001 there is a significant decrease in the number of patents applied for by these companies, which levels off in 2003, the year by which the patents applied for by 2001/02 would be expected to have been published.[7]

Note that patent counts are specified by publication and not by application year. Since the time lag between application and publication of a patent document can vary for different patents, there can be patents in the same (publication) year by National Power and its successor companies.[8]

[7] According to the World Intellectual Property Organisation (WIPO), “in most countries, a patent application is published 18 months after it is filed”.

[8] A report of patents by application instead of publication year would give a more accurate picture of the situation. However, the application date is not part of the information provided in the bibliographic data concerning a patent document and in order to obtain this date, the original patent document has to be examined, a procedure which is straightforward yet time-consuming.

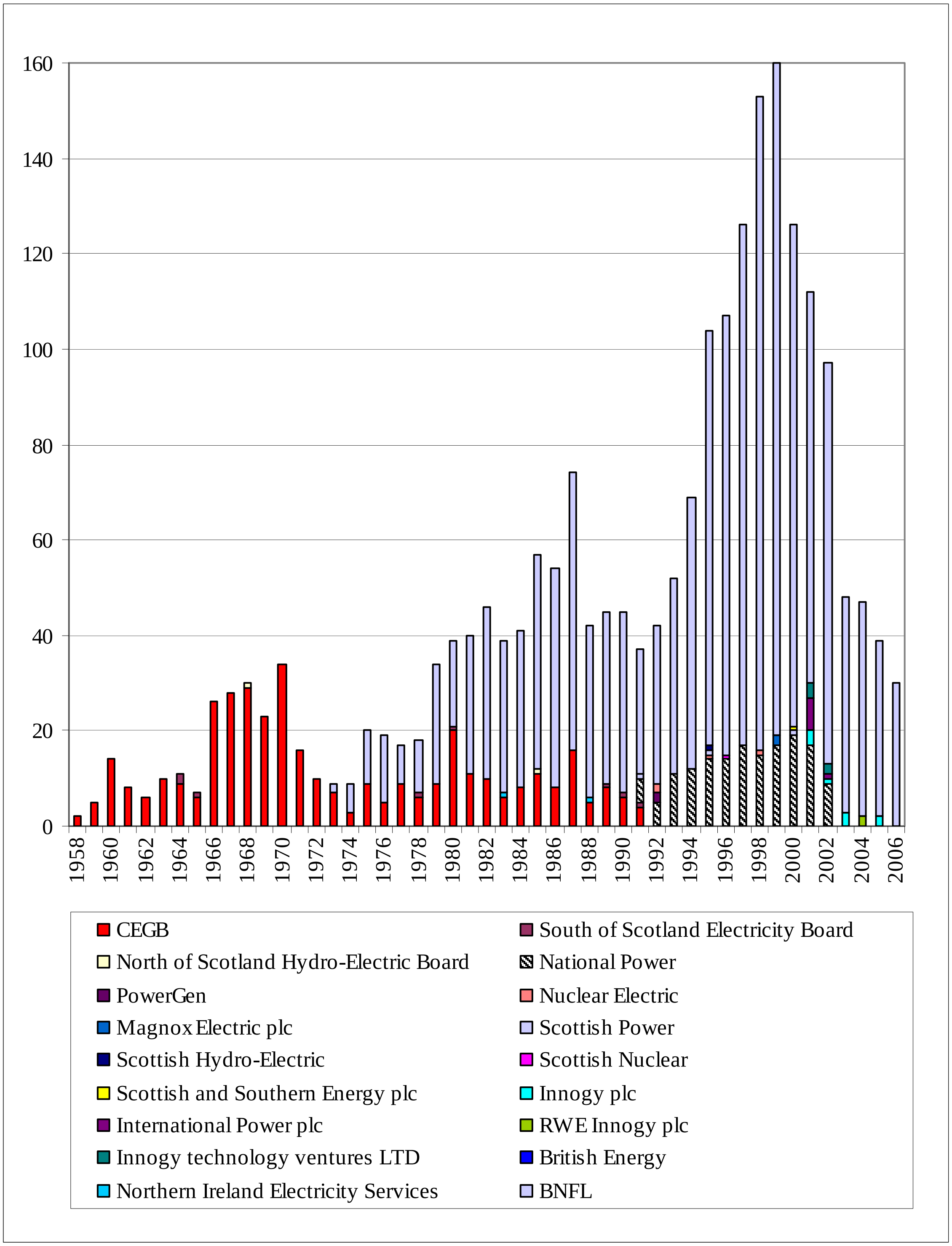


Figure 8: Patent counts by generator (including nuclear power generators)

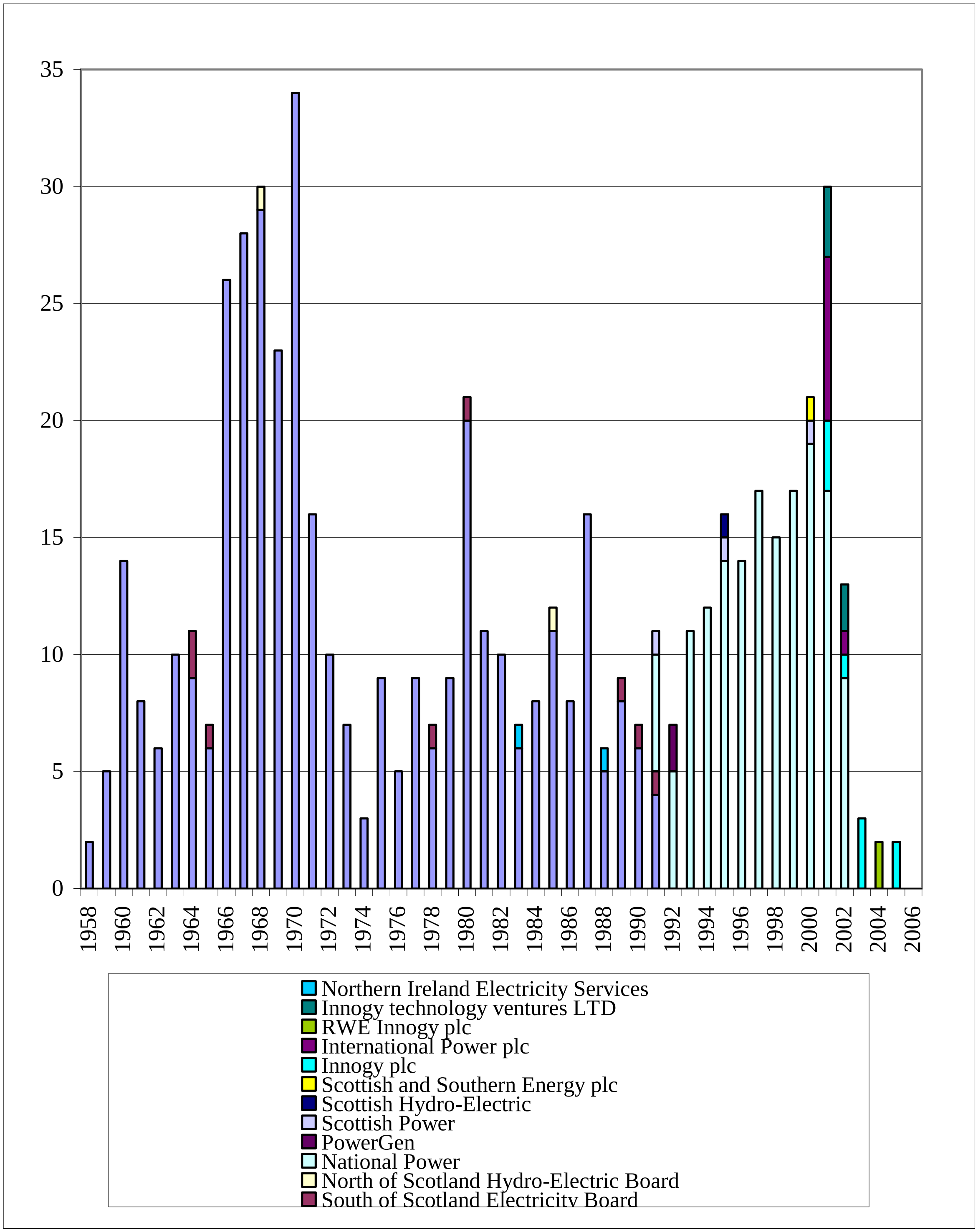


Figure 9: Patent counts by generator (excluding nuclear power generators)

5. Keyword Based Search of Sector and Technology Level Patents

In the previous section we examined the patenting activity of the major utilities and actors in the UK electricity sector. However, it is possible that liberalisation has led to a shift or migration of patenting activities in the sector. Given the potentially large number of all the relevant entities, a search of the patent databases by patentee (applicant) – as in the previous section – becomes difficult.

As mentioned previously, it will also be useful to broaden the scope of the investigation of the patenting activities to include all types of actors in the sector such as upstream electricity equipment manufacturers, technology companies, and research institutes as well as contributions from other industries. Therefore, a keyword search of the patent database, as described in Section 2.1.2, is a suitable approach for a broad and comprehensive analysis of sector-level patenting activities.

5.1 Sector level search of esp@cenet database

For some time patent information was not available at a national level but only at a worldwide and European level through the WIPO (World Intellectual Property Organisation) and the EPO (European Patent Office) databases. Esp@cenet is a network of patent databases where this information can be searched. Access has recently been extended to include all national databases that are available and it is now possible to search, for example, the UK patent database. However, this facility only allows searches of the bibliographic data of GB patent documents. Moreover, the use of the UK database does not allow searches to be performed either in the abstract field or in the European Classification field.

Given the above limitations, although the focus of our study is on UK patents, it is in practice preferable to search the network of worldwide databases rather than the UK database alone. While the worldwide databases cover information about published patent applications from over 80 different countries and regions, it is possible to truncate the search results to patents filed in the UK by requiring that either the publication or application number of the document begins with the acronym "GB". This acronym denotes that the document has been filed with the UK Intellectual Property Office (UK IPO).

This procedure would retrieve patent documents filed in the UK by applicants of any nationality. In order to further limit the results to documents filed in the UK by UK applicants, one can require that the applicant of the documents retrieved by a search are of UK nationality by inserting "[GB]" in the "Applicant" field. However, there are a non negligible number of documents - especially from earlier years - for which the applicant's nationality is not specified and these documents would be omitted from the search even if the applicant were of UK nationality. In most cases the country where *priority* (the earliest filed patent application for an invention which is claimed if protection rights are also claimed in other countries) is claimed and the nationality of the applicant coincide.

In this paper we focus on patents with GB in their nationality number and GB in their priority number. It also is possible to search for documents with UK priority, by inserting "GB" in the priority number field (a priority number is one or more of the application numbers for which priority rights are claimed) and subsequently dropping documents whose applicant's nationality (i.e. affiliation) is different than UK after examining the original patent document.

5.2 Selecting the keywords

There are two main steps involved in determining the keywords to be used in the Boolean search of the online patent databases:

1. *Specifying the preliminary sets of keywords and Boolean operators (or/and/not) to be used in the Boolean search string.* This requires taking into account:

    - The desired level of granularity of the analysis that will be reflected in the choice of keywords. In our case, given the general scope of the study, broad terms need to be used. Margolis and Kammen (1999) (see also Section 2.1.1) provide useful insight into the nature and degree of generality of the keywords to be included in patent searches.

    - The limit of 4 keywords that can be included in the Boolean search string (as opposed to 10 keywords in USTPO).

Care should be taken with regards to the trade-off between: (i) maximising the retrieval of relevant results on the one hand, and (ii) minimising the retrieval of irrelevant results on the other. Clearly, the resulting patent documents retrieved by a keyword search are bound to exclude some relevant results as well as include some irrelevant ones. However, to the extent that the distribution of such patents over the years remains stable, they are not expected to significantly affect overall trends. Moreover, given sufficient time to inspect each of the documents, all irrelevant ones can be excluded ex-post.

2. *Evaluating alternative preliminary sets of search terms and determining the set to be selected by using data concerning patents filed by CEGB as a reference point.* This requires the following:

   - Use alternative sets of keywords while requiring in parallel that the applicant is CEGB (search type A).

   - Then compare hits of the latter search to those retrieved when only requiring that the applicant is CEGB (search type B).

   - Select the set of terms that maximises the number of CEGB patent documents retrieved when conducting search type A.

Following steps 1 and 2 as described above, Table 3 shows the resulting Boolean search. The search string in the table identified 67% of the total CEGB patents filed in the UK. The respective fraction is 55% when the same string is used to retrieve patents filed by the Electricity Council.

electric* and (generat* or energy or electricity)

Table 3: The Boolean search string for electricity related patents

The results of this search method for UK electricity related patents are shown in Figure 10. As shown in the figure, there is a downward trend in UK patenting activities towards the late 1980s (left axis). It should be noted that the search string used (Table 3) does not seems to capture nuclear power related patents hence the patent numbers in Figure 10 are closer to patent numbers in Figure 9 than those in Figure 8. Following liberalisation there is a slight increase in and then a return to a stable patenting activity level. It is noteworthy that until the 2000s, the trends in the electricity related and those in the ‘F’, ‘G’, and ‘H’ categories in the European classification (right axis) follow roughly the same path. However, from early 2000s, we observe an increased activity in electricity related patents in contrast to the trend in the three broader patent categories.

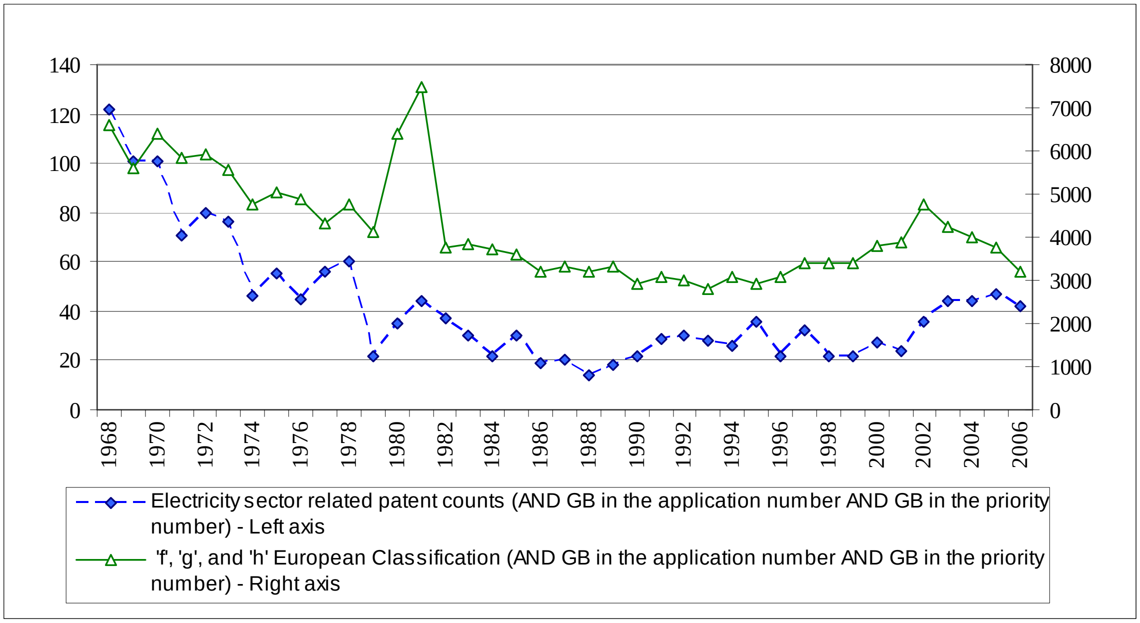


Figure 10: UK electricity related patents and ‘F’, ‘G’, and ‘H’ category European classifications (UK applications with UK priority number)

Figure 11 also suggests a somewhat similar development. The share of the UK electricity related patents of the total UK patents from all patent classes declines towards liberalisation. This share then rises until around 1995 before declining again around 2001 and then recovering in recent years.

Thus the findings of our broad-based search of electricity related patents is generally in line with the previously presented results obtained from the actor-based patent search method. Both methods suggest a downward patenting activity trend towards liberalisation followed by increased activity in the post-reform years. The increased commercialisation and competitive pressure appear to have led to higher patenting activity among the electricity sector actors and at the overall sector level in the immediate post reform years, but this declines sharply in the most recent years.

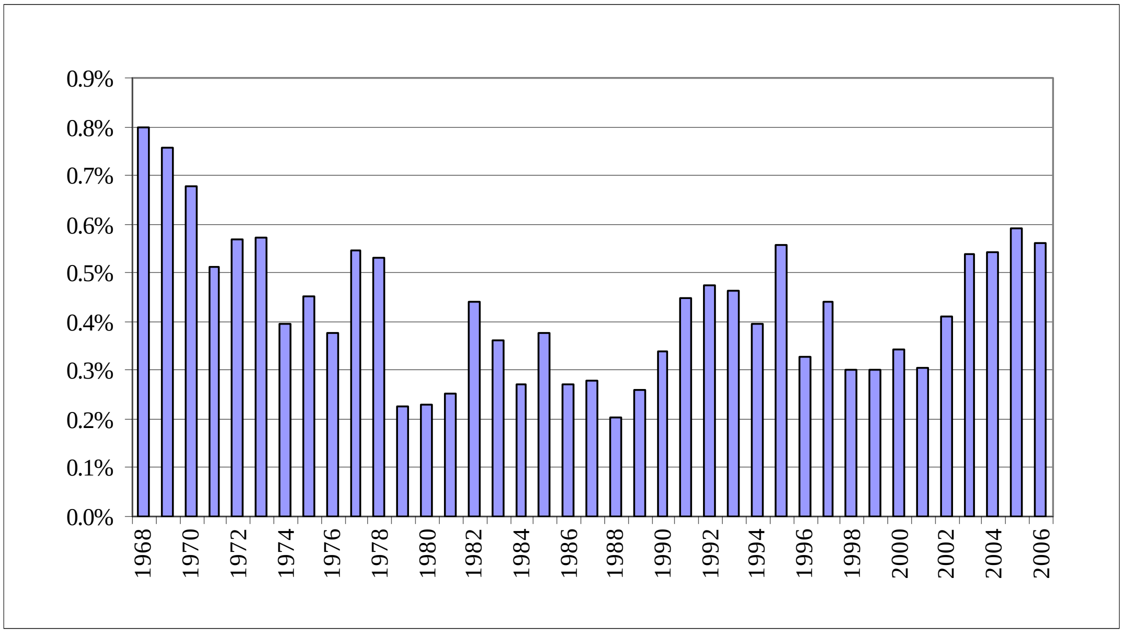


Figure 11: Electricity related patents (UK applications with UK priority number) as % of total patents of all classes (UK applications with UK priority number)

5.3 Keyword-based search of patents in specific technologies

The focus of this paper is on the broader aspects of patenting activity in the electricity sector and its relation to the liberalisation of the sector. We also noted that the main driver of liberalisation was to improve the economic efficiency of the sector rather than to promote technological innovation or renewable energy sources. However, in recent years a number of technology push and market pull support mechanisms have been established to support development and deployment of renewable electricity technologies in the UK. Johnston et al. (2008) demonstrated such effects at the level of European countries. Here we show the anecdotal evidence on the response of innovative activity in the form of patenting to policy incentives.

We examine the patenting trend of two specific renewable technologies i.e. wind and photovoltaics. Neither of these technologies is part of mainstream competitive electricity markets but are dependent on specific market pull incentives. Wind power has achieved cost reductions in recent years and has received much attention as a potentially major source of renewable electricity. It has benefited from R&D support and capacity deployment support such as renewable obligation certificates. Photovoltaics are, on the other hand, more costly and have mainly benefited from R&D support. The technology specific search is in similar to the general keyword-based approach, but with a different level of granularity which is reflected in the choice of keywords. Again, for the same reasons explained in Section 4.1, the worldwide esp@cenet databases were searched, while requiring both application and priority numbers to begin with "GB". Table 4 presents the keywords used to search for patent counts of wind power and photovoltaics technologies.

Technology	Boolean search string
Wind	wind and (power* or generat* or turbine)
Photovoltaics	photovoltaic or (solar and (panel or cell))

Table 4: Boolean search strings used for wind and photovoltaics related technologies

The results of the patent counts are summarized in Figure 12. We find that wind power and photovoltaics technologies experience somewhat higher patenting activities during the 1980s and 1990s. Also, although photovoltaics have only benefited from R&D, both technologies show a similar and marked increase in the level of patenting from around the year 2000. Thus, the limited results suggest that patenting is more a function of R&D than of capacity deployment promotion.

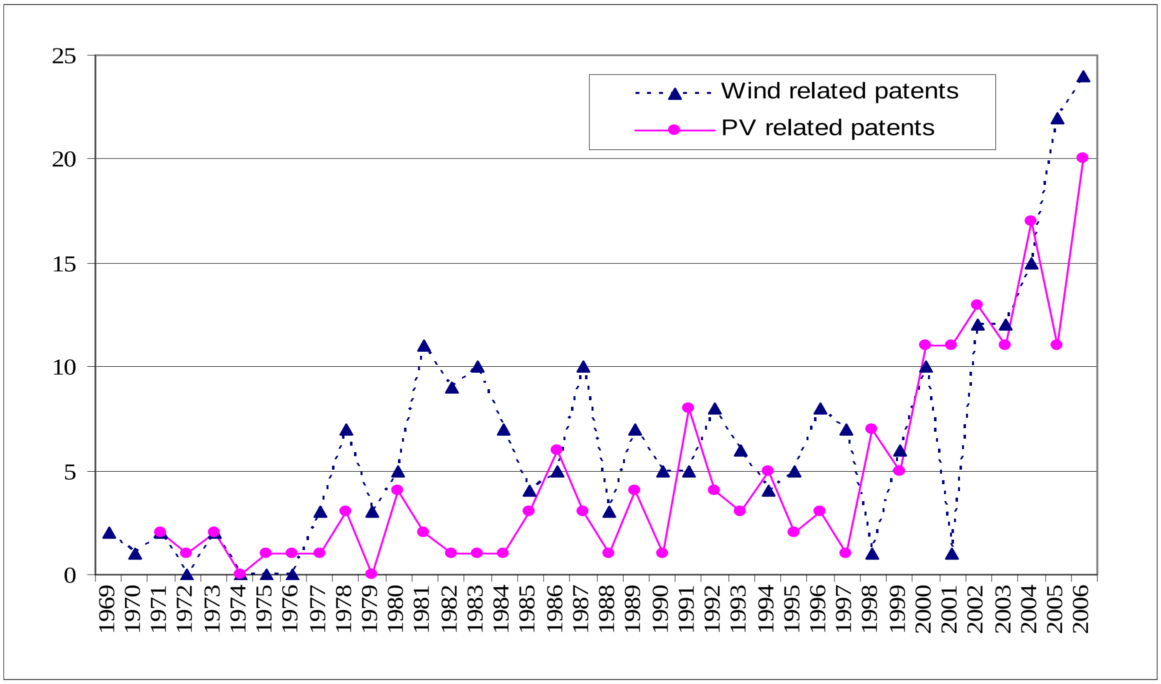


Figure 12: Count of UK's wind and photovoltaics patents

6. A Framework for New Energy Technology Innovation Systems

As we noted earlier, the innovative input in the form of energy R&D spending had already begun to decline prior to liberalization of the electricity sector. The trend continued in the years following the reform. On the other hand, the innovative output in the form of patenting activity increased as a result of their commercial value in the post-liberalization era. However in recent years the level of patenting by the sector has dropped following the passing into foreign ownership of the largest generating company. Also, in the absence of a sustained flow of R&D and in particular basic research in the mid- to long-run, the level of patenting activities would inevitably be reduced.

At the highest level, the issue of energy innovation in the UK is linked to the overall innovative activities in the economy. In 2002, the number of the UK patent applications per million labour force to the EPO was 251. Meanwhile, the corresponding figures for the EU-15 (335), EU-25 (284), Germany (619), the Netherlands (469), France (327), and Italy (198) indicating generally lower patenting in the UK (EUROSTAT, 2006a). Therefore, there is a need for a shift with regards to innovation in the economic and public policy arena. In the absence of such a shift energy R&D and innovation will find it difficult to break away from the prevailing economy-wide level of innovation. Evidence suggests that higher R&D activities lead to higher patenting. EUROSTAT (2006a and b) show a positive relationship between gross domestic expenditure on R&D per inhabitant and patent application in Europe and in the US. Also, Margolis and Kammen (1999) have shown a positive relationship between overall R&D spending and patents in general and in energy in particular in the US.

In the case of the two renewable technologies examined we noted that patent activities seem to respond to R&D (technology push) and economic incentives (market pull). At its simplest form, the remedy to promote energy technology and innovation is to increase the level of R&D spending. These lead us to suggest that some form of intervention based on the public good argument may be warranted to reverse what might otherwise be a lasting reduction in innovative activity in the UK electricity sector.

The profit incentive of liberalisation has shifted the balance of innovative activities more heavily towards the customer end of the value chain in the sector (Jamasb and Pollitt, 2008).

Also, energy security and climate change challenges have given an increased focus on innovation in renewable energy sources. New technologies will not be limited to electricity generation but will have implications for the whole of the electricity system. By some accounts (see Jamasb, Nuttall and Pollitt, 2008) future electricity systems will be characterised by active and intelligent networks accommodating a responsive industrial and household demand, micro-generation technologies, small-scale industrial and commercial combined heat and power (CHP), decentralised renewable sources, smart meters, and advanced information and communications technologies.

Moreover, as we have pointed out the R&D intensity of the energy sector is among the lowest of all industries. Not all reasons for this are apparent but some of them may lie in the particular characteristics of the electricity industry. For example, the rate of growth in electricity markets of developed countries, where most of the innovative activities take place, is slow and the economic life of the assets is long. Also, entry barriers in the energy utilities sector, whether in the energy market or the equipment manufacture markets, are high. Entry barriers to basic and applied energy research are likely to be even higher.

An obvious remedy to promote energy technology and innovation is to increase the level of R&D spending. However, this should not mean a full return to the previous R&D and innovation arrangements. Rather, the economic, technological, and policy aspects of the post-reform electricity sectors differ considerably from those of the pre-reform period. Therefore, there is a need for a new framework and policies to structure the innovation systems while taking the particular characteristics of the electricity industry into account.

Although, we still lack a robust theory of innovation, it is important to balance the technology push and market pull aspects of technological innovation. This requires an allocation of resources between different technologies and their stages of development according to expected returns. Jamasb et al. (2008) ask whether the current allocation of resources between technology push and market pull measures for new technologies in the UK is effective. In an analysis of the UK energy innovation system, Foxon et al. (2005) identify support gaps between the demonstration and pre-commercialisation stages as well as between the pre-commercialisation and supported commercialization stages. Also, a recent review of energy R&D in the UK points to insufficient R&D funding and demonstration, discontinuity and short longevity of public R&D programs, and complex energy R&D funding arrangements with a range of bodies being involved in different stages of energy technologies and innovation (European Commission, 2008).

During the 1990s, the research labs associated with CEGB and UK Atomic Energy Research Establishment (AERE) were broken up, redirected, or closed down as an unintended consequence of competition policy in the sector. At the same time, the government has in the past shown that research institutions in other areas can be reformed. Government research labs such as the National Physical Laboratory or labs of the former Defence Evaluation and Research Agency were successfully modernized within a similar timeframe. In the latter case, this was achieved via part-privatisation and in the former by a shift to Government-Owned Contractor-Operated (GOCO) arrangements (Wallard, 2001).

In a liberalised electricity sector a centralized innovation framework will not be very effective. While the public sector will have an important role in promoting innovation, the role of market mechanisms and financial incentives should be central to devising energy technology and innovation policy. The newly established Energy Technologies Institute (ETI) to promote applied and pre-demonstration research is a positive step towards bringing academic and other stakeholders around priority research areas. The energy regulator Ofgem's introduction of the Innovation Funding Incentives (IFIs) scheme and Innovation Zones which allow the regulated utilities to spend 0.5% of their revenues on R&D projects is a positive development (Jamasb et al, 2008).

As mentioned, basic research in conventional energy technologies is resource intensive and is likely to go beyond the means of most utilities and small or medium-sized companies. However, it is possible that the R&D threshold for some new and emerging technologies is lower than that of conventional technologies. For example, a carbon capture and storage demonstration facility will cost several hundred million pounds to implement. In contrast, technologies such as micro-generation, solar, fuel cells, and wind tend to be comparatively easier to research for smaller firms. However, as large multinational companies increasingly aim to include new technologies in their research and asset portfolios smaller firms may find themselves at a competitive disadvantage.

The cluster of technology firms in Cambridge, home to a major concentration of technology firms in the UK and Europe, with the exception of some activity in energy efficiency, shows very little activity in clean energy. Only about 3% of the venture-backed firms in the Cambridge cluster are classified under energy (Library House, 2007). Given the policy interest and support mechanisms for new energy technologies in recent years this appears to be very low. This may be a reflection of some of the particular characteristics of the electricity sector discussed above but also indicates that it is important to overcome the barriers and increase the number of R&D-active energy technology firms.

A useful policy approach would be to promote collaboration between the energy technology firms and the universities. For some small-medium enterprise (SMEs), the cost and effort involved in securing intellectual property arrangements and patents may lead to the lack of cooperation or to choosing secrecy over seeking patents (Foxon et al., 2005). Experience shows that the presence of an active university research environment is important for formation of clusters of technology firms (CBR-CIHE, 2008). Therefore, part of university research policy could be aimed with a view to improving research collaboration and ventures between universities and the private sector.

Finally, it should also be noted that non-technical aspects of energy technologies are increasingly important for the future direction of the sector. There is a considerable need for types of research whose output and outcome is not measured in terms of patents such as developing new business models, suitable regulatory frameworks, financial innovation, and political economy considerations, such as public acceptance and perception of energy technologies and policies.

7. Conclusions

Liberalisation of the electricity sector has had a marked effect on innovative activities in the industry. R&D and patenting activities are generally regarded respectively as innovative inputs to and outputs from technological progress.

In liberalised electricity sectors the traditional centrally planned models of organizing innovation systems are unlikely to produce the desired outcomes. R&D activities will to an increasing degree be characterised by market failure. We noted that liberalisation has accelerated an already declining trend in R&D activities. This paper examines the effect of reforms on patenting activity in the UK electricity sector. The results indicate that electricity-related patents as a whole and those specific to non-nuclear and renewable technologies initially increased in the post-liberalisation period. We attribute this trend to increased commercialisation of the sector.

We also argued that while the initial increase in patenting activity productivity is a positive development, in the long run a lasting decline in R&D spending can eventually lead to a reduction in patents and innovation. This may be happening in recent years as overall electricity patenting and patenting by electricity supply companies has fallen back, at the same time as much of the UK electricity sector has passed into foreign ownership.

In order to maintain and/or increase the pace of innovation, we discussed the need for a framework for innovation systems that is commensurate with the incentive mechanisms of a liberalised sector. We also pointed to the potential of university-based research and the synergies in innovation systems with technology clusters. Correcting the effect of market failure in R&D still requires government intervention in the innovation system. However, the nature of public sector involvement in liberalised electricity sectors needs to be different from the models used in the past. Modern technology and innovation policy should aim to create an enabling framework for innovation systems to utilize the power of economic incentives on specific actors more effectively.

Energy patent information can also be used to examine other aspects of innovation in the sector that were beyond the scope of present study. For example, patent data can be coupled with R&D spending and scientific publication data to obtain a fuller picture of innovation and the effect of energy and technology policy on innovation at the national or international level. In addition such data can be utilized to study technological progress using more advanced forms of learning curves.

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