Why and How to Subsidise Energy R+D:

Lessons from the Collapse and Recovery of Electricity Innovation in the UK

Tooraj Jamasb

Durham University Business School

*Michael Pollitt**

Cambridge Judge Business School

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Abstract

The UK electricity sector liberalisation was a pioneer in the worldwide reform trend and its reform model and outcomes have been the subject of many studies. However, lesser known are the effects of privatisation, market based reforms, and incentive regulation of networks on research and development as well as patenting activities in the sector. This paper updates our previous studies of this subject and discusses the recent developments in the innovative activities in the UK electricity sector. We find that, in recent years, the initial absence of support policies and the subsequent decline in innovation efforts in the aftermath of the reform has resulted in efforts towards forming an energy technology and innovation policy. Although we already observe some positive outcomes from these efforts, we discuss whether the balance of the innovation efforts are calibrated appropriately and whether the institutional framework can be further improved to promote long term progress.

Key words: Energy technology, innovation, liberalisation, research and development

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* Corresponding author. Michael Pollitt, Cambridge Judge Business School, Trumpington Street, Cambridge CB2 1AG, Phone: +44 (0)1223 339615, Fax: +44 (0)1223 339701, Email: m.pollitt@jbs.cam.ac.uk

1. Introduction

In this paper we revisit and update some of the research and findings from our earlier papers that documented the theoretical and empirical effects of electricity market liberalisation in the UK (Jamasb and Pollitt, 2008 and 2011). Those papers highlighted very significant falls in both public and private R+D in the electricity sector following the privatisation and restructuring of the electricity utilities in the UK around 1990. We showed that both public and private R+D expenditure fell and how this eventually worked through to a large fall (by the year 2000) in patenting by the successor companies created out of the restructuring process. We also noted how strategic subsidies to renewables seem to have supported an increase in patenting by non-utilities and how there seemed to be much less effect on total electricity patents across the economy as a result of what was happening in the electricity supply industry. Our empirical observations were taken up by regulators (in energy and water)[1] in the UK and used to support the case for the subsequent significant increase of support schemes for utility RD+D projects.

New studies of innovation, drawing on developments in the ICT sector, suggest that different types of innovation can be distinguished and that these require the support of different types of institutional set ups. Meanwhile there has been a significant recovery in electricity R+D expenditure from a global low point (around 2004) and this seems to be generating more innovative output in terms of patents. The present paper revisits and builds on our earlier theoretical and empirical observations in the light of the subsequent developments in theory of innovation and in evolution of electricity R+D in the UK. The main aim of this paper is, however, to update the policy lessons to be learned and shed further light on exactly why and how governments can support innovation in the electricity sector.

[1] See Cave Review (2011) for water.

What follows is organised in four main sections: Section 2 discusses the theory of energy R+D expenditure, innovation and productivity; Section 3 reviews the recent empirical evidence on energy R+D expenditure and innovation output and energy market reform; Section 4 discusses what the society can do about supporting energy R+D. Section 5 presents the conclusions and some future directions for energy innovation.

2. A Brief Review of Links between Energy R+D Expenditure and Innovation

While the economic and environmental benefits of developing new energy technologies and increasing the efficiency of the existing ones are substantial the level of R+D investments appears to be low. In economic terms, this represents a case of market failure where private discount rate for R+D efforts is higher than the social discount rate mainly due to uncertainty in the outcomes and the ability to appropriate the benefits. Indeed, energy is already one of the least R+D intensive industries. Part of this investment inadequacy may be due to the relatively slow rate of growth for conventional energy technologies in the mature markets. Moreover, inadequate institutional framework and policy and regulatory uncertainty can further add to this disparity in discount rate between private and public R+D spending (see Gallagher et al., 2012 and PCAST, 2010 for good overview discussions on the energy innovation system, with suggestions about how and why to increase R+D expenditure in the context of the US).

Dooley (1998) first highlighted the empirical observation that energy market reform in advanced countries had produced an unintended consequence in the form of a decline in energy R+D expenditure. In Jamasb and Pollitt (2008a) we discussed that the theoretical conditions for an increase in private energy innovation activities from privatisation and liberalisation of the electricity sector were not observed in practice. Indeed, we have seen that progress was only visible where an active public sector engagement was present. While the need for continuous public sector involvement is now widely accepted, the discussion is increasingly focused on the form and instruments of public support. In practice, this debate has manifested itself in discussions of the relative merits of supporting R+D activities versus offering subsidies for energy generation from renewable technologies. In other words, a key aspect of the debate is whether public involvement should take the form of stimulating learning-by-research versus learning-by-doing - i.e. technology push versus market pull instruments respectively (see Jamasb, 2007).

Total global fossil fuel subsidies in 2013 were $548bn (IEA, 2014, p.313). By contrast total renewable energy subsidies in 2013 were $121bn (IEA, 2014, p.). Total Industrial Energy R+D in 2012 was only $20.6bn (Battelle, 2013), with total OECD Government Energy R+D in 2011, being a further $18.6bn (IEA Statistics). Thus given the importance of R+D knowledge stock in driving cost reductions (and service quality improvement), there might be a compelling case for continuing and, even, increasing government support for energy R+D rather than offering subsidies to consumption and production of conventional or renewable energy. There is a well-documented link between energy R+D and energy innovation, as measured by patents (see Namet and Kammen, 2007, who show this for the US).

Recent literature has highlighted the high interdependence between public and private R+D. Even in the EU where public research and development has fallen sharply since 1990, public R+D in 2007 was still 44% of total Strategic Energy Technologies (i.e. non-conventional technologies), with most corporate R+D being concentrated in wind, PV, biofuels, CCS and smart grids where strategic deployment was heavily subsidised (see Wiesenthal et al., 2012). Interestingly, Popp et al. (2011) show that innovation output (as measured by the stock of patents) is only weakly related to the installed MW of renewable energy, indicating that it is the R+D expenditure push and not the installed MW base pull that is driving innovation.

However there are different types of innovation (Bauer, 2012). Some innovation is modular, while some is coordinated. Some is incremental in nature and some is radical. Each type of innovation requires different types of market and government support. Public R+D support may be particularly useful in some areas (e.g. for radical coordinated research), but not relevant in others (e.g., for incremental modular research).

These ideas link with suggestions for assisting new technologies with crossing the 'valley of death' as they move from research projects to technologies being deployed at scale. Both PCAST (2010) and Weyant (2011) note the potential role of increased funding for post-graduate research as a low risk way to stimulate energy innovation. However US commentators including Alic et al. (2010), PCAST (2010) and Weyant (2011) suggest the importance of looking to recreating the public-private dynamic observed in semi-conductors and IT in the 1950s and 1960s between the US Department of Defence and its private contractors, which provided long term support at scale for costly innovation. The idea being that energy innovations are, initially at least, public goods best procured from the private sector directly rather than indirectly if innovation is to be sufficiently rapid. In this spirit, PCAST (2010) recommend the need for a Quadrennial Energy Review (inspired by the Quadrennial Defence Review) to co-ordinate federal energy policy. Arguably this sort of co-ordinating role is already being undertaken in some EU countries by other agencies, such as the Climate Change Committee in the UK.

A further key idea (Acemoglu et al., 2012) is that there is a path dependency in technological innovation. This means that subsidising 'clean' inputs vs 'dirty' inputs may shift technical change on to a different pathway. This may involve shifting research scientists from working on dirty technologies to clean ones. This may be cheaper in the long run than direct support for existing clean technologies.

Thus while electricity sector reform has reduced R+D by conventional utilities and by governments, climate and renewable policies have strongly stimulated R+D expenditure and innovation since 2000. Dechezlepretre et al. (2011) show that countries with stronger climate policy exhibit more patenting for thirteen climate-mitigation technologies. In particular the share of their technologies in all innovations doubles from 1990 to 2005, back to the rate of 1980. Dechezlepretre and Glachant (2014) note that both global and national policies influence domestic innovation. They find that a 10% increase in wind power capacity globally is associated with an increase in domestic wind innovation of around 6%.

3. Empirical Evidence on R+D and Electricity Market Reforms in the UK

3.1 Electricity and Gas market reform in the UK

The UK electricity industry was substantially reorganised beginning in 1990. The Central Electricity Generating Board (CEGB), which had a monopoly of electricity transmission and production in England and Wales, was broken up and privatised. This created four successor companies (three in generation and one in transmission). The regional monopolies – which had owned generation, transmission, distribution and retail supply - in Scotland and Northern Ireland were also substantially reorganised and privatised by 1993.

The structure that emerged in the years following privatisation was one of a competitive wholesale market, largely separate transmission, regional monopolies in electricity distribution and competitive retail markets (later re-integrated with generators when this was allowed). Effective competition in both electricity generation and supply significantly increased with new entrants becoming particularly significant in the generation market. Meanwhile independent economic regulation increasingly focussed on the transmission and distribution networks.

The gas supply sector went through a similar process beginning with the privatisation of the monopoly incumbent, British Gas, in 1986. Following this a competitive wholesale gas market emerged and the former gas supply business competed strongly in the retail electricity market, just as former regional electricity supply monopolists entered the retail gas market. This led to utilities with interests in gas and electricity markets emerging. In the period since reform all new fossil fuel power stations built in the UK have been gas-fired, increasing the relationship between the electricity and gas sectors.

In 1999 the independent gas and electricity regulators were merged to form Ofgem. In approving the revenue control formulae of regulated energy network companies Ofgem has been responsible for approving and overseeing the level of R+D expenditure of this paper of the electricity sector.

Gradually climate concerns increased (in line with the rest of the EU) and subsidies to renewables were substantially increased from 2002 and the sector was subject to the EU Emissions Trading Scheme from 2005. As a result the amount spent on subsidies to the deployment of renewable forms of electricity substantially increased from less than £100m in 2000-01 (Pollitt, 2010) to around £2.5bn in 2013-2014[2]. In 2008, the UK Climate Change Act set up 5-year carbon budgeting for the whole economy and established binding 2020 and 2050 whole economy targets for decarbonisation. The Committee publishes detailed policy recommendations, many of which relate to the power sector. In 2013, an Electricity Market Reform (EMR) – driven by the ambitious national decarbonisation targets - was enacted which

[2] See https://www.ofgem.gov.uk/publications-and-updates/renewables-obligation-total-obligation-2013-14. Accessed 27 January 2015.

introduced new mechanisms for supporting a 90% decarbonisation of the electricity sector by 2030 (see Pollitt and Haney, 2013).

3.2 R+D expenditure

In this sub-section we will review and update the evidence on the decline and partial recovery of government energy R+D expenditure across the world since 1980. Figure 1 shows the significant decline in R+D expenditure between 1990 and 2000, followed by a marked recovery in R+D expenditure between 2000 and 2010. In every country in the graph the total energy R+D is above the level of 1990 by 2010 in real terms. The rise is however less than the growth in GDP. If we take 1990 to be the starting date of liberalisation of energy sectors we can see that this picture is consistent with liberalisation initially having a large negative impact on R+D expenditure, followed by a period of recovery inspired by rising prices of energy and rising concern for the environment.

The ERMine Report (2008) found that total electricity R+D expenditures in the EU declined substantially between 1985 and 2004 at the electricity supply industry, national government and EU levels. However, the industry's original equipment manufacturers (OEMs) maintained their expenditure in real terms. For example, in 2004 euros, expenditure at the ESI level fell from 3774m to 1063m; at the national government level expenditure fell from 4692m to 1916m; while the EU funding fell from 557m to 425m; R+D spending by OEMs remained at around 7900m in both years.

Figure 1: Government energy R+D (2012 mil. USD)

The detailed picture for government energy R+D in the UK is shown in Figure 2. As shown in the figure, the trend to reducing R+D was already manifest by 1980 and that government R+D expenditure in real terms has not recovered to the level of 1980. However, stripping out nuclear research, the R+D expenditure is at record levels by 2010, and is significantly driven by renewable and energy efficiency research.

Figure 2: Government energy R&D in the UK - Main categories (£m 2008 prices)

Obtaining accurate figures on private energy R+D is extremely difficult, especially as government R+D may be carried out through private entities. Private R+D and government R+D have tended to be closely related and complementary in the past (see Jamasb and Pollitt, 2008). Indeed, government R+D should also be designed to promote private R+D initiatives that otherwise would not have been implemented. Government R+D may also be used to promote more private R+D. Private energy R+D can be carried out by a variety of new entrants, international equipment manufacturers and utility companies. Energy market liberalisation (of both electricity and gas supply sectors) has stimulated entry to energy markets, internationalised procurement and internationalised utilities, making the relevant measures of private R+D expenditures for any given country increasingly difficult to estimate on a consistent basis.

The easiest type of private energy R+D to measure at the national level is that of utility companies. Figure 3 shows this decline in the UK following the privatisation of electricity generation and transmission companies. This has not recovered significantly in the 2000s, mainly due to the fact that passing into foreign ownership of much of UK generation. This has meant that the capacity to do research in the UK subsidiaries of large foreign companies (EdF, RWE, E.ON and Iberdrola own most of the UK fossil fuel generation fleet) has been lost.

Sterlacchini (2012) notes the decline in R+D expenditure by major utilities at the global level between 2000 and 2007. EdF alone saw its R+D / sales ratio fall by 50% in seven years. Grosse and Sevi (2009) note the same findings for a sample of 14 European utilities.

Figure 3: R+D spending in major UK generation and transmission companies

(£m 2008 prices)

Similarly Kim et al. (2012) discover a significant negative correlation between entry market liberalisation and R+D expenditure for a sample of 70 electricity generating firms from 15 countries, over the period 1990-2008. They suggest that the introduction of a wholesale market, regulated third party access (TPA) and retail market deregulation each produce negative effects, but that the effect of the wholesale market is the most negative for R+D expenditure by the firms. Sanyal and Cohen (2009) show large declines in aggregate US utility R+D expenditures and demonstrate that these are negatively affected at the time of deregulation for a sample of 195 utilities from the period 1990-2000.

However, in recent years, there has been a recovery in R+D expenditure by distribution network utilities as shown in Figure 4. The recovery is, however, from rather low levels, but it is a significant trend and has resulted directly from regulatory intervention to stimulate innovation (partly inspired by analysis showing the extent of the initial decline in R+D spending) to allow upgrades to aging networks and facilitate development of smart grids.

Figure 4: UK Distribution company spend on network R+D in mil. of £2008 (IFI projects only)

It should be recalled that the electricity networks are natural monopoly activities and thus their prices and revenues are subject to economic regulation by the sector regulator OFGEM. This has important implications for R+D spending incentives among these utilities as such expenditures need to be approved by the sector regulator. The non-competitive nature of the networks also implies that collaborative R+D must be encouraged as this increases the scale of innovative efforts and does not run the conventional risk of non-appropriation of the R+D benefits. Indeed, this risk is one of the main reasons for the social discount rate on R+D expenditure being lower than that of private discount rate, leading to public intervention and support at the first place.

Figure 4 shows the impact of the one of the major funding initiatives – i.e. Ofgem's Innovation Funding Initiative (IFI), where distribution utilities were able to recover up to 90% of their innovation spending (subject to a maximum of 1% of turnover) from customers from 2005. Additionally, a new scheme, the Low Carbon Networks Fund (LCNF) aims to allow an additional £64m per annum for the 2010-15 period to be spent by electricity distribution utilities on large scale demonstration projects. This would take expenditure by distribution utilities at least to levels far above that spent prior to their privatization in 1990.

3.2 Innovation output

What effect has this collapse and recovery of investment in R+D had on innovation in the electricity sector? This is difficult to measure because it may be that much of this expenditure is not aimed at producing patentable (or even publishable) output. IFI and LCNF projects in electricity distribution are mainly about trialling of new concepts and near market technologies produced by OEMs. The OEMs own the technology and the distribution companies are effectively subsidised to use these. Therefore, measureable innovative outputs may be hard to come by.

Patents (and other quantifications of innovative output) have well known draw backs as measures of innovation. Nelson et al. (2014), in the context of 'green chemistry', discuss how innovation measurement is subject to the following biases: obliteration - the failure to quote true origins of an idea, but merely quoting derivative work, thus undervaluing the significance of the original invention; and symbolic adoption – the use of fashionable keywords in patent descriptions which leads to misclassification of patents. This means that keyword based searches may fail to correctly classify patents. This idea remains to be explored and developed further in the electricity innovation literature.

Figure 5 shows patenting by the main utilities in the electricity sector in the UK. Clearly the decline and recovery in R+D expenditure has impacted patenting by the private successor companies to the formerly state owned industry. Basically the successor companies have stopped producing patentable innovations and that this has not been changed by recent increases in funding. The nature of innovation in the electricity industry has been fundamentally affected by liberalisation. A significant part of this is the permanent collapse of nuclear R+D expenditure but non-nuclear actors have also ceased to patent.

Figure 5: Number of patent applications from main UK ESI actors, by type (1958-2013)

The R+D expenditure statistics showed the large surge in renewable expenditure in the years up to 2010. Figure 6 shows the remarkable effect of this on innovation for just two technologies – wind and PV. It is interesting to track the close relationship between patenting and expenditure. Expenditure shows local real peaks in 1980 and 2010, while patenting activity also shows local peaks one year later in 1981 and 2011. The targeted recovery in expenditure seems to be associated with even higher levels of patenting than immediately prior to privatisation. This may reflect a positive relationship between R+D expenditure and profitability, identified for a sample of US renewable energy firms in Apergis and Sorros (2014) for the period 2000-2012.

Figure 6: Number of UK wind and solar patent applications

Can we say anything about the overall effect of the pattern of energy R+D expenditure on total UK electricity and renewable energy innovations? One attempt to do this is shown in Figure 7. This shows that in spite of the initial collapse of public and utility energy R+D expenditure following privatisation this did not noticeably affect the relative significance of electricity patents in total UK innovation (an effect noted by Jamasb and Pollitt, 2011). However the recent focussed R+D expenditure recovery is significantly associated with historically unprecedented levels of innovative output. Grosse and Sevi (2009) suggest a similar pattern might be observed at the EU level where energy technology patents increase between 1995 and 2007, but the share of utilities in this declines from 30 to 3%.

Figure 7: Electricity and renewable energy related UK as % of total UK patents publications

The above statistics raise fascinating questions about research productivity (innovative output / R+D expenditure) which seems to have increased significantly. Even though electricity R+D expenditure as a percentage of GDP has fallen since 1990, the innovative outputs have risen significantly as a percentage of total patents. The ending of large scale research and development efforts into nuclear power in the UK are a significant part of this. Newbery and Pollitt (1997) similarly noted that the ending of the nuclear power building programme at privatisation contributed to a third of the benefit of privatisation. However the targeted efforts to support research into renewables (and perhaps also on distribution systems) may also be part of the story.

There has also been considerable global patenting by leading international OEMs. This has significantly increased since 1990 as can be seen in Figure 8. This provides evidence that there is likely to have been a migration of innovation from utilities to their equipment suppliers, who are themselves increasingly global players. Thus while R+D expenditure and patenting by UK utilities may have fallen, their equipment suppliers have been doing more patenting. Some of this may have occurred in the UK, however Figure 8 shows that the UK share of this increase in global patenting is negligible and declining. Equipment manufacturers are patenting but their research is not being done in the UK.

Figure 8: Patents by 6 leading international electricity OEMs and share of these in UK

A number of papers have explored the link between environmental policies and patenting in a time series analysis of international data. Johnstone et al. (2009) find that both renewable energy credits (tradable green certificates) and Feed-in-Tariffs promote innovation for a panel of 25 countries, using data from 1978-2003. While Nesta et al. (2014) find a positive correlation between market liberalisation and patents for a similar dataset. They suggest that policies to promote renewables are more effective in more competitive final energy markets. This result is appealing in terms of its justification of policy trends towards liberalisation, but leaves open the question about whether countries with better renewable resources are likely to have more competitive final energy markets and hence this is an endowment effect rather than a policy effect.

These international results are apparently contradicted by US evidence on OEM innovation and its relationship to US electricity market deregulation. Sanyal and Ghosh (2013) find innovation by a sample of OEMs declines following the 1992 deregulation and that this is correlated at the individual firm level with deregulation. The total effect is apparently large at around minus 20%. This is made up of a pure competition effect driving down OEM profits, an escape competition effect due to the increased value of innovation in a competitive setting and an appropriation effect where new entry pushes up the returns to innovation and a one off effect of deregulation. Of these, the first three effects basically cancel each other out for a sample of around 1800 OEMs over the period 1976-2000. However the paper fails to explain the large rise in innovation between 1986 and 1992 prior to deregulation: in 6 years innovation rises by around 50%.

Lee and Lee (2013) present interesting innovation trends in total US energy patents. The number of patents have risen between 1976 and 2010 across a number of important technology categories. Most interestingly there have been large increases in wind, solar, fuel cell and power system technologies. This indicates that energy innovation remains very healthy in aggregate terms but much of it is clearly not being undertaken by the OEMs. For

Germany, Wangler (2013) analyses 5 renewable technologies – including wind and PV - over the period 1990-2005 and finds that policy induced demand has stimulated innovation as measured by patents.

4 How Should the Society Support Energy R+D? Lessons from the UK's Low Carbon Networks Fund

Following Nelson (2008) it is helpful to distinguish between 'physical' technology and 'social' technology. The difference between the two can be illustrated by the example of delivering a recipe (a 'social technology') as distinct from tools ('physical technologies') to make food. Old social technologies may not be appropriate and may need to be replaced by new ones in the face of new innovative challenges to deliver new societal productivity goals (such as rapid, cost effective decarbonisation). The PCAST (2010) proposal in the US for a Quadrennial Energy Review as a coordinating mechanism is an example of 'social' technology to deliver better energy outcomes. It is clearly a throw-back a previous era but it may still be appropriate in the US social context.

Energy innovation challenges also require the right institutions and innovation ecology to enable new developments to occur. Public R+D expenditure may be necessary in the face of the 'fundamental uncertainty' of innovation (which may be particularly true in the context of decarbonisation). It should be noted that only a small number of sectors drive productivity in any historical period. In the current period innovation in energy could be particularly rapid if it exploits the huge advances in information technology. A combination of private and public actions on expenditure and in institutional support is required, but public actions can also be wrong ones (hence misdirecting R+D effort). A focus on institutional arrangements suggests that innovation policy is not primarily about the amount of R+D expenditure but also, to a large extent, about the way it is directed.

The allocation of public sector support to energy R+D and production subsidy measures needs to be better informed and balanced by economic principles and empirical evidence of their relative productivity and return. Jamasb (2007) showed that the cost reduction effect of learning-by-research for new technologies can be stronger than the learning-by-doing effect. Jamasb et al. (2008a) have previously pointed out the highly uneven distribution of public funds in the UK among these two broad types of instruments and questioned the economic logic of this practice. The changing nature of the underlying technologies at the centre of energy research – specifically the decline in nuclear R+D and the rise in renewables R+D – suggests that older institutional arrangements are unlikely to be appropriate for a new operating environment and that new ways of organising research and innovation activities are needed to promote rapid technological progress.

The UK's Low Carbon Networks Fund (LCNF) initiated by the energy regulator is a good example of creating a new institutional arrangement aimed at improving the social technology around energy innovation that is delivered via electricity networks. Under this fund, during the 2010-2015 price control, according to the regulator, Ofgem[3], 'up to £500m to support projects sponsored by the Distribution Network Operators (DNOs) to try out new technology, operating and commercial arrangements'. This increased by a factor of five in the previous level of annual support for such R+D. The fund covers smaller projects decided by individual DNOs (First Tier) and an independently assessed competition between DNOs for funding for larger projects (Second Tier, up to around £50m). There remain the important questions of who should pay and how for these, substantial, research funds. LCNF projects are customer funded.

[3] Source: https://www.ofgem.gov.uk/electricity/distribution-networks/network-innovation/low-carbon-networks-fund. Accessed 27 January 2015.

This is in effect a regressive tax related to energy consumption. The RD+D benefits are uncertain and are shared across the economy (esp. when projects fail in their own terms). The benefits are often not in lower price of energy (which justifies payment in proportion to use), but in security and environment which are public goods whose individual value is income elastic. Benefits are often delayed for decades which means that the current poor consumers will not be able to benefit. LCNF type funding *may* have transaction cost savings in collection and monitoring but these are not clear (i.e. they may be marginally cheaper to collect and monitor using existing systems). However, overall *public* RD+D should come out of general taxation.

However, we observe that collaborative private RD+D is possible. This can occur where a special purpose vehicle is formed in order to undertake a large scale pilot project, independently of a dedicated funding stream such as LCNF. An example of this is the £16m eFIS EV project in Milton Keynes in England led by Arup and Mitsui (Miles, 2014). In this pilot project an electric bus is provided to the local bus company under an innovative energy service contract, where the bus and its associated charging infrastructure are provided by private technology partners for the bus company to operate. The project also includes data gathering and analysis and is undertaken in collaboration with the City Council. In the absence of explicit encouragement from national public policy, such arrangements may only be possible in certain jurisdictions where transaction costs are low. This is because of the veto power over such local innovation that could be exercised by incumbent service providers, local distribution utilities or municipal authorities, whose collaboration is essential to going ahead.

Indeed the recent planned measures for curbing the total cost of subsidies for renewable energy sources in some European countries such as the UK, Spain, and Germany reflect the increasing weight of these expenditures on public sector budgets. The total cost of energy production or capacity subsidies have been increasing despite the reductions achieved in the unit cost of renewable energy. Concerns about fuel poverty explain the current pressure to cut back on renewable subsidies, particularly in the EU.

5 Conclusions and Directions for Energy Innovation Research

5.1 Linking to productivity in energy services

All discussions on energy R+D and innovation beg the question as to how they relate to the productivity of energy services in the electricity sector. However, this is a difficult empirical link to make because the lag effects are likely to be long and variable. Also, a single country's innovative activity may not be particularly significant in terms of determining energy productivity given the globalisation of technology.

What is needed is to link the work of economic historians on productivity in energy services (e.g. Fouquet 2008, 2011, 2013 for the UK) with the R+D and innovation data we have discussed in this paper. A key problem in measuring electricity service productivity is around measuring the quality (or in the case of nuclear power the safety) of the output. This is especially important given that much recent innovative activity has focused on environmental improvements, particularly in terms of emissions reduction in the generation process (of sulphur dioxide, nitrous oxides and carbon dioxide, i.e. SO_X, NO_X and CO_2). In nuclear power, strengthening of safety standards has been a major reason for a lack of decrease in cost of nuclear power. Fouquet (2011) focuses on long run trends in external costs associated with coal use in Great Britain. He examines mortality due to coal mining and mortality due to associated air pollution. External costs associated with coal production and use peaked in 1891 at 17.5% of GDP (Fouquet, 2011, p.2385). These costs have fallen rapidly since 1950 to near zero by 2000. This massive improvement in environmental effects should be accounted for in any reckoning of energy service productivity. Indeed Newbery and Pollitt (1997) found that around one-third of the benefit of CEGB privatisation arose from the reduction in SO_X and CO_2 emissions resulting from the privatisation.

Given the large observed increase in innovation associated with wind and solar technologies further sources of 'quality' improvements need to be looked at. Renewable energy innovations may produce significant learning benefits in terms of future cost reductions and may be associated with energy security savings and supply chain benefits (Duffield, 2008). Higher short run financial costs may indeed be associated with non-financial benefits which need to be valued in order to evaluate at the impact of R+D expenditure. However, the work of incorporating this into productivity growth in energy services remains to be done.

5.2 Why and How to subsidise energy R+D?

Having revisited the practice and evidence from energy R+D in recent years we offer a number of conclusions and suggestions as to where future energy innovation is needed and how this may be structured. Directed technical change is important but subsidised R+D is *only one* way to achieve this. R+D expenditure in energy did decline following liberalisation, but this has now partly recovered albeit in a different form. This is because profit incentiveshave shifted R+D resources to near-market innovation have increased the productivity of R+D.

R+D *probably* requires some government sponsored support mechanisms. However, the main role of government involvement should be to support basic research where the incidence of market failure in R+D is the largest. Also, public funds should be used, to the extent possible, to encourage private R+D. However, this should not take the form of simple subsidies for R+D that would have taken place in any case. An important use of government support is to encourage collaborative research. This is most needed and effective in the case of natural monopoly regulated networks.

At the same time, although funding is a crucial element of any innovation policy, R+D capacity must be built up over time and be sufficient to absorb the resources. Sudden increases in funding, as observed in recent years in the UK, may have limited effect in the short and medium term. Thus, building up energy research capacity requires long-term policy stability and regulatory commitment.

It is also important to note that significant technological progress is not only about the underlying technology, there remain important economic and social issues that need to be addressed. The final recommendation of PCAST (2010) highlights the need for more research on the social science of energy technologies in the US context.

Jamasb et al. (2008b) have assessed the technical, economic, and social barriers to the development and adoption of new energy technologies. Indeed, there are already many signs and indications that the adoption of technology and the usage behaviour of consumers regularly defy conventional theoretical economic and social science predictions. R+D policy should include substantial research into the economic and social interface of the technology and its intended users.

Therefore, energy R+D needs to pay attention to 'social technology' given the lessons from innovation in information technology and the path dependency of existing energy systems. There are some key areas where the social science of energy could innovate, with a view to promoting energy productivity. Three such areas where innovation is needed are worth noting: the need to improve governance and payment arrangements in energy (e.g. by the development of the role of system operators or the introduction of nodal prices); innovation in the use of information from smart grids and smart meters (e.g. in pricing schemes or load control); and improvements in policy making in the face of rising complexity of regulatory decision making (e.g. more use of customer engagement or better regulatory cost benefit analysis). Some of these sorts of innovations are incremental and some are radical, while some are modular and others require coordination.

Finally, it is important to note that although more R+D may be desirable this is not necessarily synonymous with better or the right type of R+D. In electricity technology and innovation, there is an appropriate R+D role for the different actors and stakeholders. For example, the type of R+D that the utilities engage in should often be different from that of equipment manufacturers, universities, local authorities, and consumer groups.

The division of the R+D roles for these actors should take into account the primary function and comparative advantage of these actors. For example, the universities are better placed to conduct basic research while the private sector is more incentivised to conduct near market research. This organisation based around capabilities and comparative advantage should also reflect the differences in risk, potential rewards, and time scale of their R+D. In basic research the risks of R+D are higher while the rewards occur in the long run and have public goods properties. On the other hand, for private sector the risks in near market R+D are comparatively lower and their benefits occur in short and medium term. In contrast to this, in practice, in recent years, the UK university funding mechanisms have required and promoted more immediate and tangible economic impact from academic research. Such diversion of academic research capacity to near-market applied research may come at the expense of lower long term benefits from basic research which would otherwise have fed future applied R+D.

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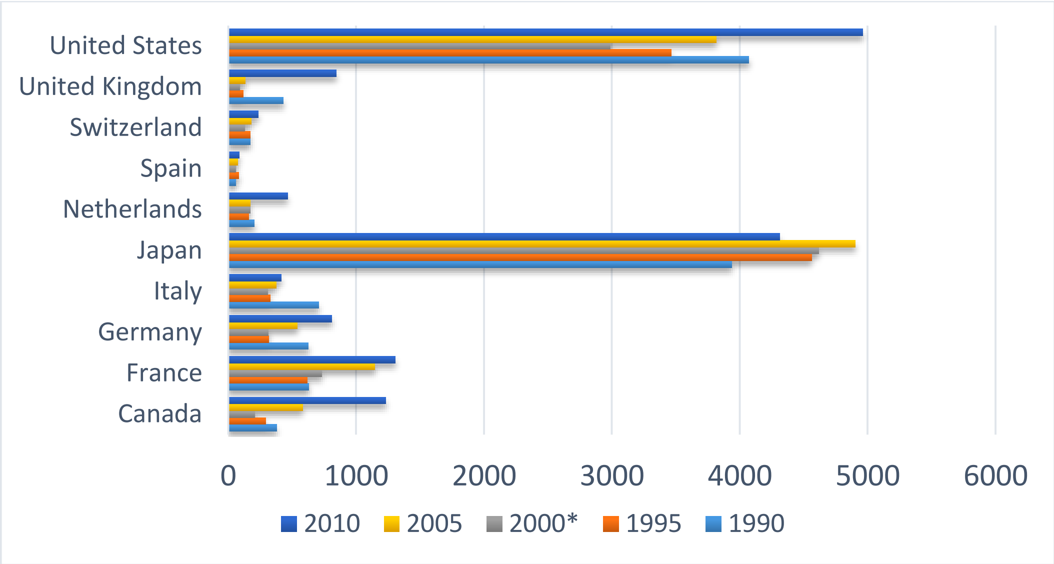
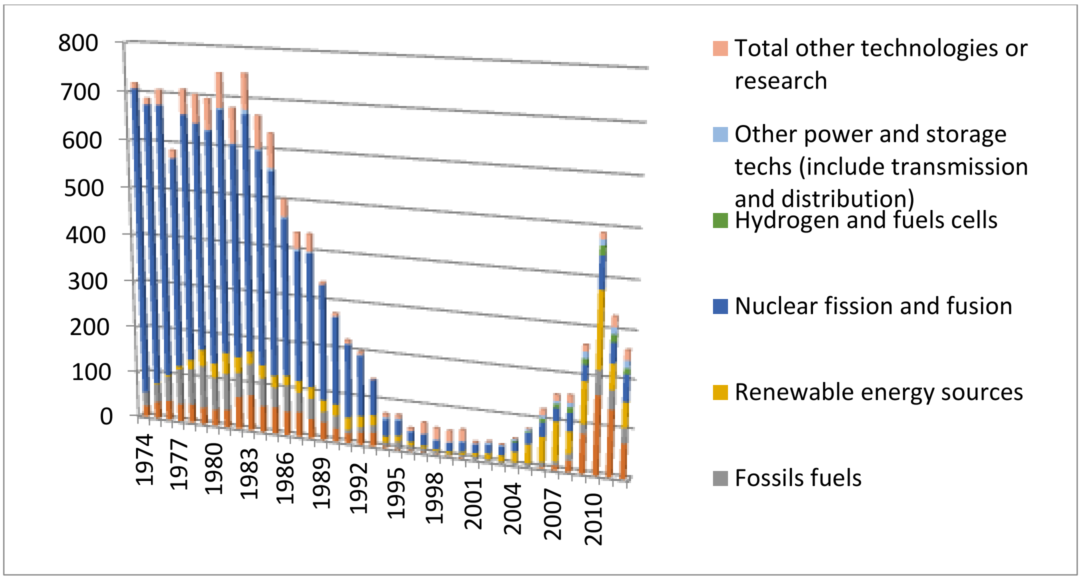
Figure 1: Government energy R+D (2012 mil. USD)



Source: International Energy Agency

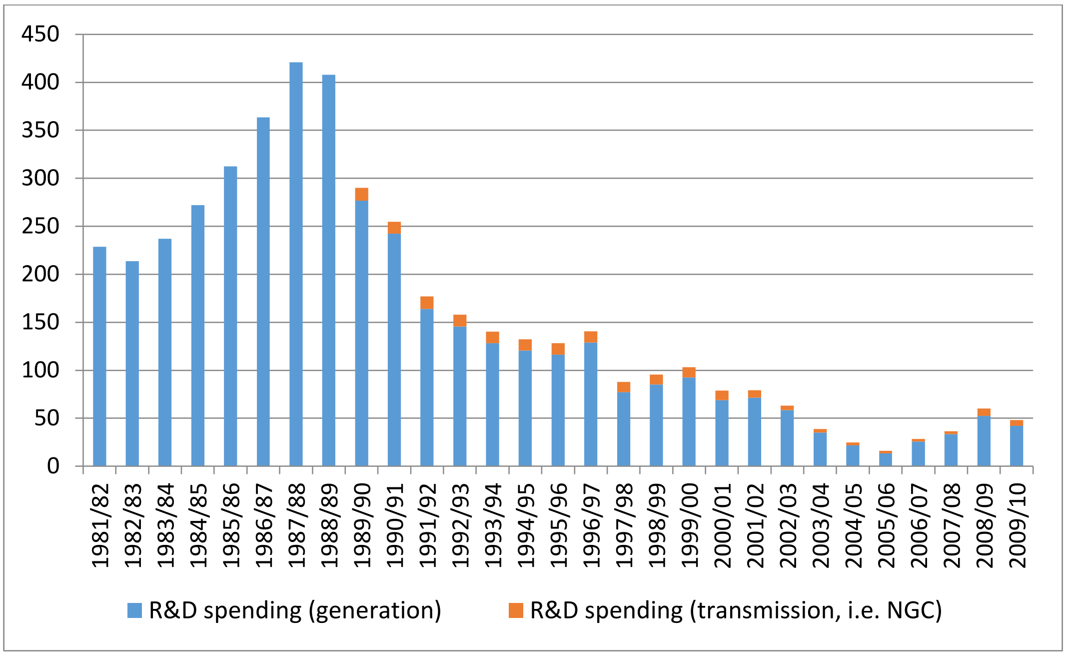
Figure 2: Government energy R&D in the UK - Main categories (£m 2008 prices)



Source: IEA Energy R&D statistics database

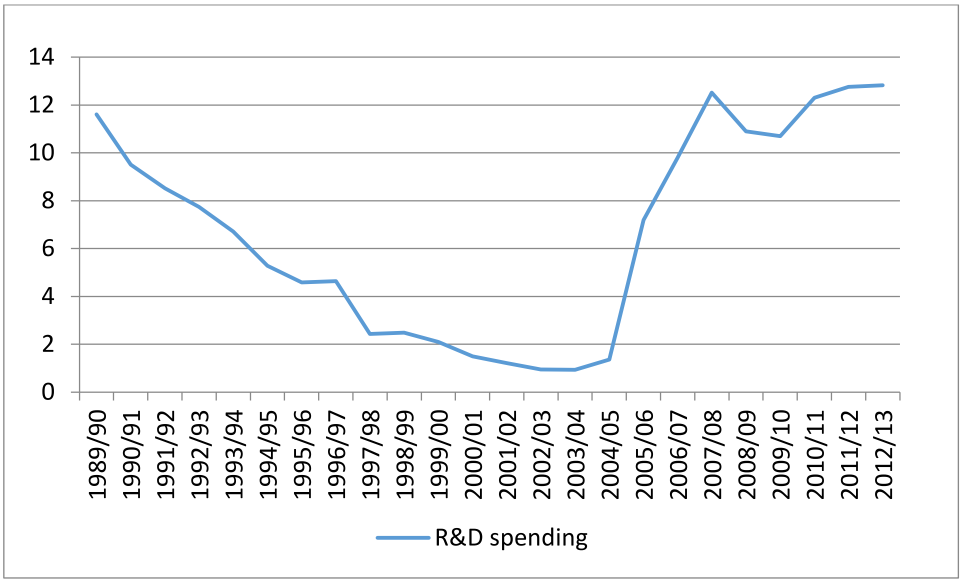
Figure 3: R+D spending in major UK generation and transmission companies

(£m 2008 prices)



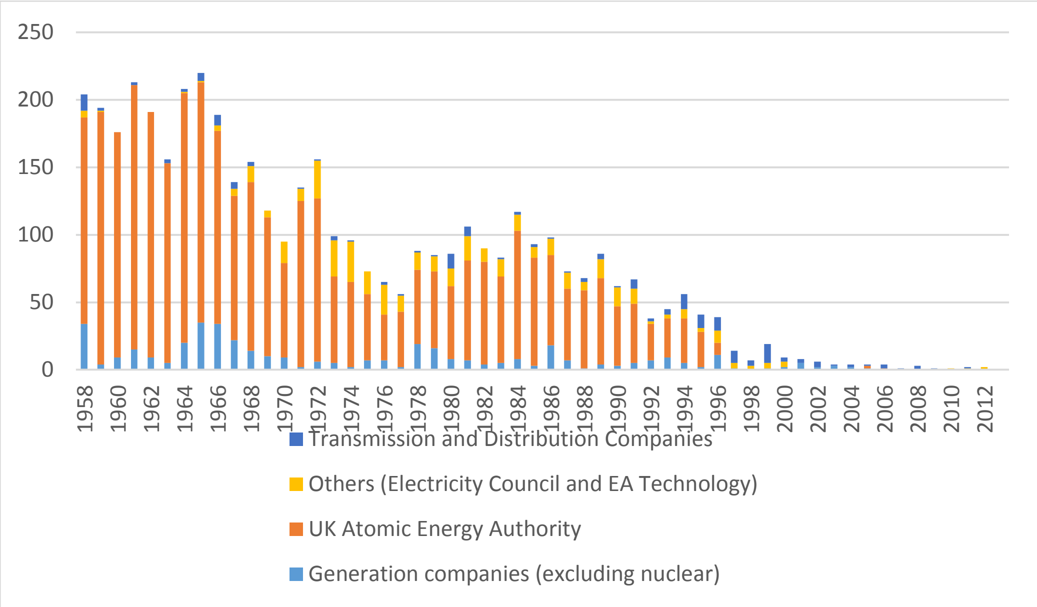
Source: Surrey (1996), CEGB and NGC Annual Reports and Accounts, BIS R&D Scoreboards, from Jamasb and Pollitt (2011, updated).

Figure 4: UK distribution company spend on network R+D in mil. of £2008 (IFI projects only)



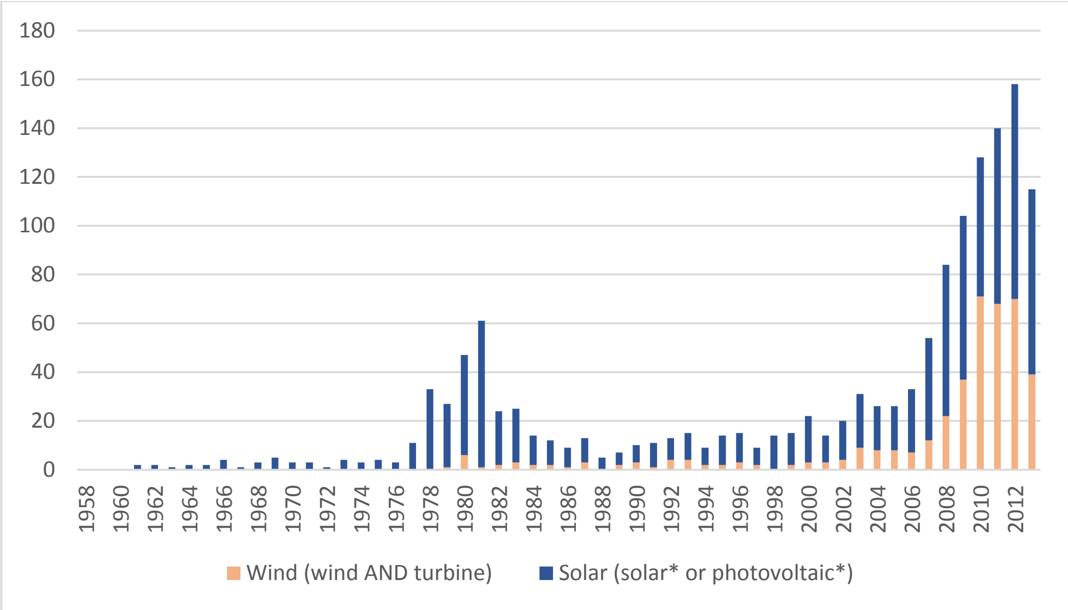
Source: Jamasb and Pollitt (2011, updated).

Figure 5: Number of patent applications from main UK ESI actors, by type (1958-2013)



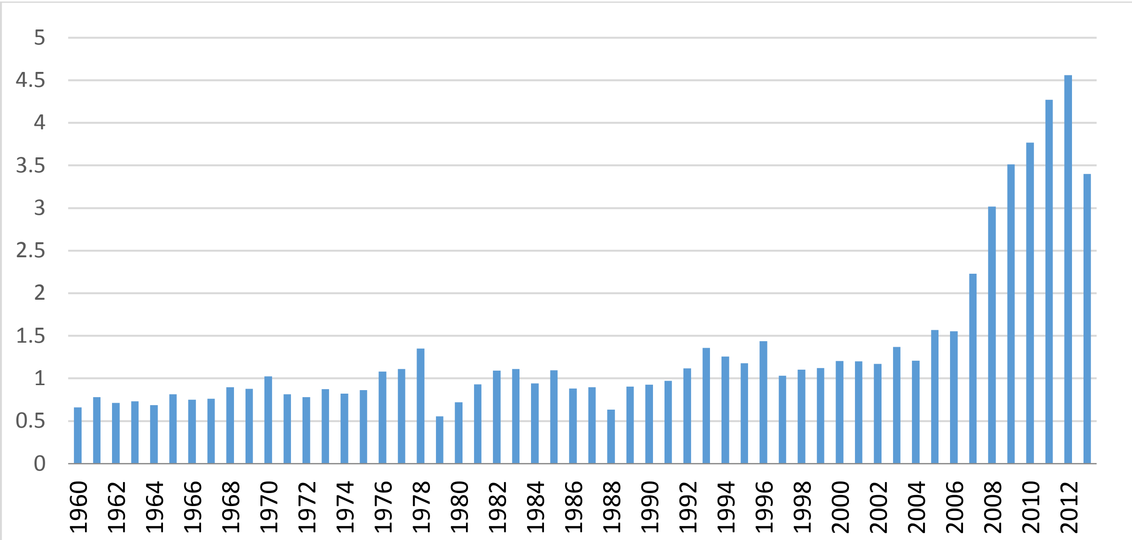
Source: From Jamasb and Pollitt (2011, updated).

Figure 6: Number of UK wind and solar patent applications



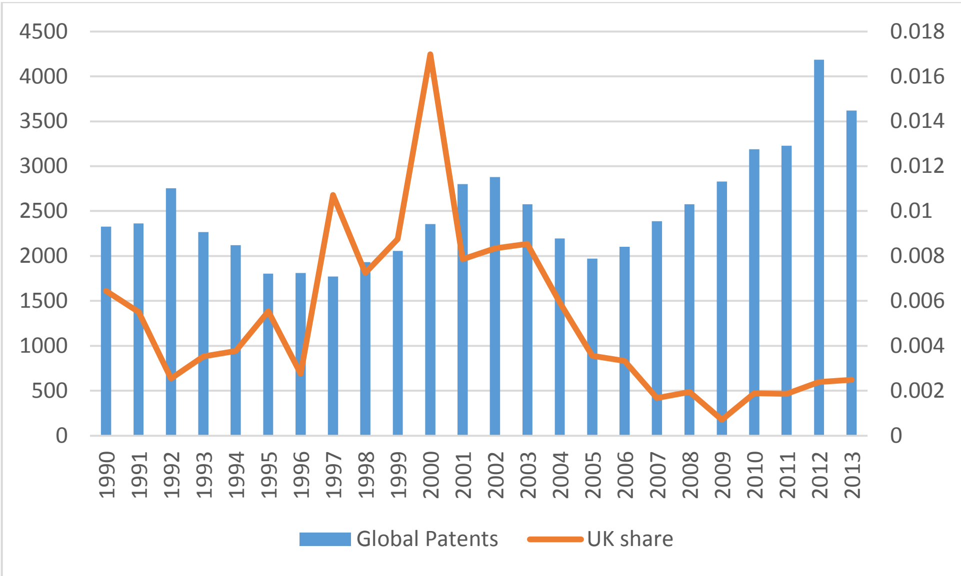
Source: Espacenet Database, search by publication year.

Figure 7: Electricity and renewable energy related UK as % of total UK patents publications



Source: Espacenet 'Worldwide' Database; Keywords 'electricity' 'solar' 'wind' 'biomass' in patent Title and Abstract and GB as 'application number' AND GB as 'priority number'.

Figure 8: Patents by 6 leading international electricity OEMs (LHS) and share of these in UK (RHS)



Source: Espacenet Database; Keyword Electric*. OEMs: General Electric, Siemens, Vestas, Mitsubishi, ABB and Alstom.