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Is Privatization enough? Finding Performance Breaks for UK Power Plants

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Abstract

The literature shows that for most UK industries privatization itself might be necessary but is not sufficient in order to produce positive net benefits. Typically prior changes in management or later changes in market structure and regulation have larger impacts than privatization itself. We ask what changes around privatization had the greatest impact on efficiency for UK electricity generators. We analyse the effects of privatization and other changes in incentives on plant efficiency using a newly compiled panel data set. We measure efficiency as input demands for two standard inputs, fuel and labour as well as three pollutants, CO_2, SO_2, and NO_x. We model the change in efficiency as a single intercept break and allow for the break to occur at an unknown date. Inference for breaks and break dates relies on Quandt-Andrews type tests. We find breaks associated with efficiency increases for fuel and labour. Breaks and efficiency changes for the three pollutants are generally related to fuel efficiency though there are instances were efficiencies move in opposite directions suggesting trade-off between fuel efficiency and emissions exist. There are no breaks prior to privatization. All breaks occur after privatization. Efficiency increases first for labour and later for fuel. We conclude that electricity privatization like other UK privatizations was a unique event. Privatization was important to prepare the ground but it seems that only the subsequent restructuring of the industry, the reduction of political interference in fuel choice, and investment in new and more efficient generation technologies increased efficiency.

Keywords: privatization, efficiency, structural breaks

JEL classification: L33, L16, L51, L94

1 Introduction

1.1 Motivation and research question

Whereas neoclassical models of profit-maximization assert that competition increases allocative efficiency they largely ignore productive efficiency. More recent models of agency assert that changes in ownership and competition also change technical or productive efficiency. Among other things the predictions of these models swayed politicians to privatize and liberalize in the 1980s and 1990s (Winston, 1993). However, both theorists and practitioners often underestimated the amount of detailed design that is necessary to establish functioning markets. An industry that needs particular care is electricity because its service is essential and the economics of supply do not necessarily square with the physics of supply. Often the failure to design markets properly brought into disrepute the entire reform agenda as for instance after the electricity crisis in California. In the UK restructuring and privatization (R&P) of the electricity supply industry (ESI) was followed by about ten years of trial and error until a reasonably competitive market without retail regulation emerged. Our research question is how and when did these trials affect plant-level technical operating efficiency? This allows us to test the assertion of agency theory that management is "effort-averse" (Fabrizio et al., 2007) and that it is private ownership combined with market rivalry that push management to live up to its potential. Unlike the work of Newbery and Pollitt (1997) or Fabrizio et al. (2007) we do not only ask how much was the impact but also when did it happen?

We study the development of productive efficiency for a sample of UK electricity generation plants from before privatization in 1985 until 2000 and map the result to the institutional changes during this period to assess their relative importance. Unlike Newbery and Pollitt (1997) we are not concerned with the overall costs and benefits of privatization but the impact on plant-level operating efficiency as a proxy for management performance. The effect of regulatory change on operating efficiency can only be disentangled at the plant level because other factors like fuel mix cannot be controlled for at a higher level of analysis. Also the contribution of plant-level efficiency gains to the overall benefits from privatization of the

UK ESI is large (Newbery and Pollitt, 1997). To our best knowledge this is the first study that takes this perspective on the privatization of the UK ESI. [3]

We model plant-level efficiency as individual input demand functions derived from cost-minimization based on a model introduced by Fabrizio et al. (2007). We extend their model by including three major air pollutants as non-traditional inputs (as opposed to traditional inputs, e.g.: fuel and labour). Also, the counterfactual is not the performance of a control group but the plant's own past performance. More precisely we search for one known or unknown structural break in each demand equation using Quandt-Andrews type test statistics (Hansen, 2001). Unlike most other privatization studies we search for a break in the data and then map it to the known event history (Freeman, 2005). One exception is Waddams Price and Weyman-Jones (1996) who use a Quandt-test to search for a break in productivity around the privatization of British Gas. Unlike most other studies of UK privatizations we do not rely on measures of labour or total factor productivity (Pollitt, 2000, p. 130). We have compiled a new unbalanced plant-level panel data set which covers about ten years before and after privatization. We find efficiency improvements for all inputs. Almost all breaks occur several years after privatization. We conclude that though privatization might have been important to prepare the ground it seems that only the subsequent restructuring of the industry, the reduction of political interference in fuel choice, the entry of more efficient generators, and the change of the wholesale trading regime increased efficiency.

The outline is as follows. Section 2 provides some background information on UK electricity privatization as well as emissions and environmental regulation. Section 3 summarizes both the relevant theoretical and empirical literature. Section 4 states our hypotheses and section 5 describes our approach and empirical model. Section 6 describes the data. Section 7 gives the results which are then discussed in section 8.

[3] We would like to thank the participants of the City University's Centre for Competition and Regulatory Policy Summer Workshop which took place in Birmingham in July 2007 for their comments and feedback. And we would like to thank Paul Kattuman and Luis Orea Sanchez for their extensive feedback. Last, we would like to thank former research assistants as well several companies for helping with the data collection. The usual disclaimer applies.

2 Background

2.1 UK electricity restructuring

This section describes the circumstances of privatization and outlines the most important events during the following decade. What stands out about the privatization of electricity is that even though it was among the last major privatizations in the UK it was the first that was accompanied by an immediate restructuring of the industry (Newbery, 2004, p. 2). Previously, most firms (e.g. British Telecom and British Gas) had been privatized as de facto monopolies. Nevertheless, as the objectives of privatization were largely political rather than economic, effective competition was sacrificed to obtain the political support for privatization (Kay and Thompson, 1986, p. 31). Margaret Thatcher herself summarized her reform agenda by saying: "Economics are the method; the object is to change the heart and soul."[4] It seems that for electricity privatization the hearts and souls of shareholders (including the government) and miners were more important than the hearts and souls of customers. Accordingly, efficiency gains from privatization were not high on the political agenda as opposed to a number of other economic and political objectives (e.g. lessening of union power and widening share ownership) as detailed by Green and Haskel (2004, p. 65). But was there room for efficiency improvements? According to Henney (1987, p. 7) political interference was pervasive in the Central Electricity Generation Board (CEGB) and there were various managerial inefficiencies (pp. 38). Pollitt (2000, p. 109) argues that there was "a lot of potential for increased productivity especially if US-style management techniques could be introduced". Newbery (1998, p. 5) on the other hand, claims that the CEGB was "moderately well operated". Cragg and Dyck (1999) argue that privatizations in the UK brought little change in governance relationships and that golden shares and dispersed ownership weakened control after privatization. However, they find that across all UK privatizations life became less quiet for managers several years after privatization. Though it seems that there was potential for efficiency improvements after privatization it is unlikely that this potential was realized early on.

Next we give a short chronological account of events. Before privatization electricity was supplied by the CEGB, a vertically integrated state-owned monopoly. As early as 1983 a new Energy Act required the regional distribution franchises (the Area Boards) to buy energy

[4] Sunday Times, 3 May 1981.

from independents at avoided cost. But for various reason this first attempt to liberalize had no lasting effect (Henney, 1994, p. 20). It is likely that a year-long miner's strike in 1984 made the government only more determined to privatize the industry. Eventually in 1990 the UK government restructured and privatized the CEGB. The industry was vertically unbundled and horizontally separated. Assets were split among four companies: all thermal plants were divided between PowerGen and National Power, the new transmission company National Grid obtained pumped storage plants, and Nuclear Electric the nuclear plants. Sixty percent of PowerGen and National Power were sold to the public in 1991. The remaining shares were sold in February 1995. Nuclear Electric was only privatized in 1996 and is not included in this study. Unlike the wires businesses of transmission and distribution, generation and supply were considered potentially competitive and entry allowed. In Northern Ireland and Scotland the electricity industries were restructured and privatised in 1991 and 1992 respectively. Pollitt (1997) discusses the case of Northern Ireland. Northern Irish and Scottish generators are included in this study.

After privatization a wholesale trading regime had to be established. The first trading arrangement was referred to as the Pool. Both the number of players and the behaviour of the Pool participants led to concerns over market power and eventually the forced divestiture of the two incumbents, National Power and PowerGen in 1996.[5] In subsequent years the two incumbents sold more generation capacity (mostly to US investors) in return for regulatory permission to re-integrate with the regional distribution companies. The overall result was that market concentration for generation decreased considerably between 1996 and 1999. The Herfindahl Hirschman index, a measure of market concentration, for coal fired plant had dropped by 1999 to a fifth of its value in 1990.

The entry of US firms also seems to have ended tacit collusion between the generators. Edison Mission bought two plants in 1999 and increased output by 30% (Newbery, 2004, p. 18). In order to improve competition further the Pool was abolished in favour of bilateral trading in 2001 (referred to as New Electricity Trading Arrangements – NETA). Ofgem (2002, p. 1) judged that in the Pool "prices had failed to properly reflect a more competitive generation market and falling generation input costs". Newbery (2004) however doubts the effectiveness of NETA and credits the increase in competition that occurred just before for lower prices. The introduction of NETA is the last major event our analysis covers.

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[5] In 1996 National Power and Powergen leased a total of 6 GW to Eastern Group (Electricity Association, 1997).

Though generation was market-driven after privatization, the overall fuel mix was not free from political interference. Figure 1 illustrates the change in the fuel mix in the period 1970 to 2005. From privatization until late 1992 and to a lesser degree till 1998 the incumbent generators were committed to buying certain amounts of British coal at above world market prices which could be passed on to captive residential customers (Newbery, 1998). It was intended to let these coal contracts expire when retail competition for all customers was introduced in 1998. At privatization only sites with loads above 1 MW were allowed to buy directly from the Pool and this threshold was lowered to 100 kW in 1994. Starting in about 1993 gas was increasingly substituted for coal (the "dash for gas") [6]. Nevertheless, in the late 1990s concerns over dwindling British coal sales and the dependence on gas lead to a moratorium on new gas-fired generation and a visible increase in coal burn.[7]

Low capital cost and low gas prices made gas the fuel of choice for new entrants. Nevertheless, the majority of new CCGT plants were built by the two incumbents because they could off-set a high gas price against the cost of retrofitting sulphur abatement technology to their existing coal plants (Bantock and Longhurst, 1995, p. 135). As new gas capacity grew much faster than demand many coal-fired plants were closed prematurely. Also, the regulator, Offer (1992, p. 15) states: "During the 1980's the CEGB compared the cost of transmission reinforcement with the running and maintenance cost of these smaller and older stations (i.e. less efficient plants) and concluded that the most cost effective way of supporting the local group demand was to rely on their continued operation." It is possible that had the industry not been restructured different trade-offs between transmission and generation would have been made and various stations would have continued operation. Last, the substitution of oil for coal during the miner's strike in 1984 is visible in the data. Overall demand has been trending upwards since the early 1980s.

[6] The move to gas was not widely anticipated as the use of gas as a generation fuel was prohibited till 1988.

[7] Fowlie (1999) reminds us that the British experience might be rather unique. She states that in the US "increased liberalization of markets through the implementation of Order 888 […] meant […] older, under-utilized coal plants are being brought back into production".

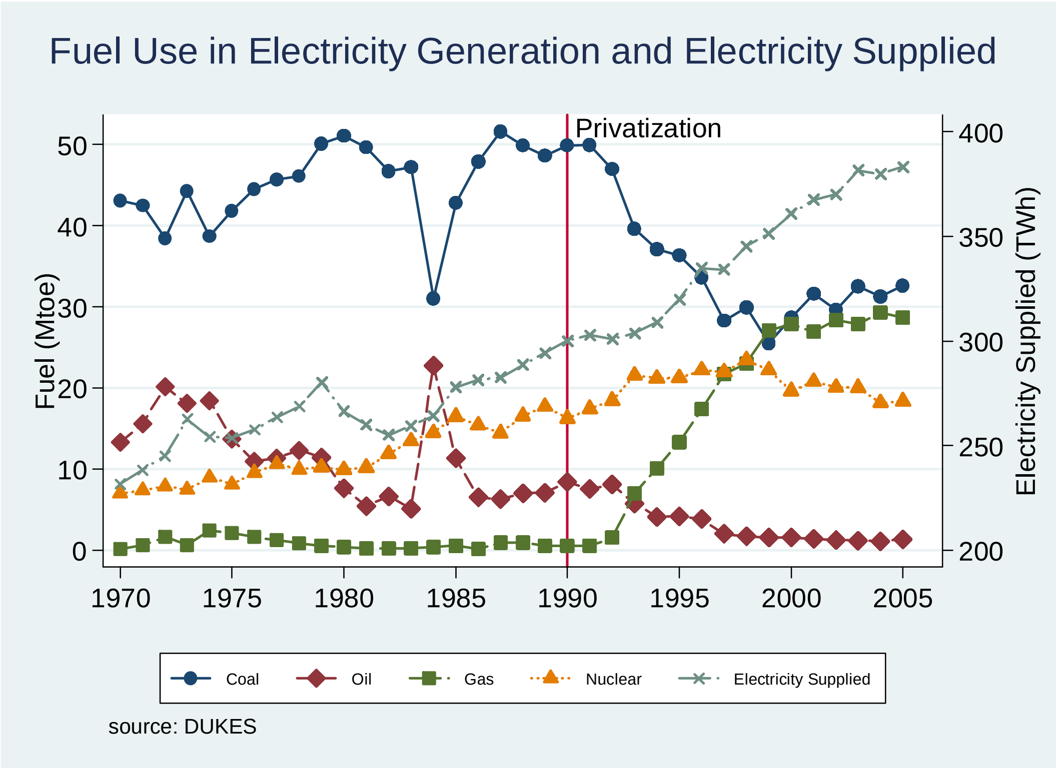

Figure 1: Fuel Use in Electricity Generation and Electricity Supplied

We summarize this section by defining three post-privatization periods. First, there is the period 1990 to 1994 when privatization takes place and the two incumbents form an effective duopoly. Then there is the period 1995-1998 when the industry is fully privatized, restructured further, and more retail competition allowed. The last period starting in 1999 is characterized by much stronger competition because of further entry and the full opening of the retail market. In the remainder of this chapter we will refer to these periods as privatization, restructuring, and competition. But this distinction is more relevant for fuel and labour than for emissions which we discuss next.

2.2 Emissions and environmental regulation

We argued above that economic efficiency was not the prime objective of privatization. This is even truer for environmental efficiency. Pearson (2000, p. 291) states: "Environmental policy considerations do not appear to have formed any significant part of the objectives that underlay privatization […]". Nevertheless, privatization unintentionally had an effect on industry emissions through changes in fuel mix and improvements in general efficiency. Additionally, privatization had an effect on the type of abatement technology installed in response to environmental regulation. Adrain and Housley (1999, p. 43) conclude that "despite the lack of a premium for environmental investments, fierce competition and the adoption of forward-looking policies have resulted in major environmental benefits".

Most UK environmental regulation is derived from national commitments under international agreements to reduce the amount of certain pollutants by a certain percentage over a certain period. Many regulations stipulate different sets of rules for existing plant and new build respectively. We focus on three pollutants: carbon dioxide (CO2), sulphur dioxide (SO2), and nitrogen oxides (NOx) which we label non-traditional inputs. Table 1 lists agreements and regulations that address these three pollutants. It is helpful to distinguish between SO2 and NOx on the one hand and CO2 on the other. Whereas the first two were targeted by international agreements already in the mid 1980s CO2 was targeted by the Kyoto protocol and in particular the start of the European Emissions Trading Scheme (EU ETS) in 2005. Thus, there has been no effective CO2 limit over our sample period. In 1990 the Environmental Protection Act introduced both plant and firm-level SO2 emission limits for coal and oil fired plant (gas emits no SO2). These limits have been tightened over time.

Table 1: Relevant Environmental Regulation for UK Power Plants

Date	Regulation	Coverage	Content
1988 (implemented by the Environmental Protection Act 1990)	Large Combustion Plant Directive (LCPD)	NOx, SO2, dust from plants with rated thermal input > 50 MW	requires the **industry** to reduce emissions in steps for existing plant (SO2: 10% by 1993, 40% by 1998 and 60% by 2003 compared with 1980; NOx: 16% by 1993 and 31% by 1998 compared to 1980), emissions limits for new plant
1994	International Protocol on Sulphur Dioxide	SO2	80% **national** reduction by 2010 (based on 1980)
1999	Gothenburg Protocol[8]	Sulphur, NOx, VOCs and ammonia	SO2: national reduction by 87% for 1980-2010, (NOx 54%), requirement of BAT
2000	Utilities Act	Energy suppliers	obligation for renewables and energy efficiency
2000	Kyoto/ additional UK targets	CO2 and other greenhouse gases	20% **national** reduction of 1990 levels by 2008/12
2005	EU ETS	CO2 and other greenhouse gases	Plant level cap and trade
2008	revised LCPD effective	NOx, SO2, dust from plants with rated thermal input > 50 MW	Opt-out possibility[9]
2008	Climate Change Act	CO2 and other greenhouse gases	80% **national** reduction of 1990 levels by 2050

Generally, there are three ways to abate at a given plant (while operating): change fuel, install abatement technology, or increase efficiency. Changing fuel implies using the same fuel but of a different quality which typically means lower contents of sulphur or nitrogen. For instance, foreign coal tends to contain less sulphur than British coal and is often cheaper. Though it might be possible to change fuel type at the plant level as well this is typically not done because plants are optimized for a particular fuel. Different fuels contain different

[8] See http://www.unece.org/env/lrtap/multi_h1.htm.

[9] The LCPD allows plants to opt-out given that they do not operate for more than 20.000 hours during the years 2008-2015 and cease operating in 2015 the latest. Plants opting out are all major coal plants not fitted with FGD: Cockenzie, Didcot A, Fawley, Ferrybridge (part), Grain, Littlebrook, Ironbridge, Kingsnorth, and Tilbury according to DTI (2006).

amounts of energy as well as different amounts of "pollutants" (see Table 2).[10] According to the DTI (1998) the reduction in CO_2 for the industry between 1990 and 1997 is two thirds due to fuel switching with the remainder due to increases in efficiency.

Table 2: Emission Factors

Emission	Emission factors (grams/GJ)		
	Natural gas	Oil	Coal
CO_2 (weight of C)	14000	19000	25000
SO_2	0	520	850
NOx	51	120	270

source: Pearson (2000, Table 21.4)

Various technological changes can be made at the combustion and post-combustion stages. At the combustion stage low NOx or sulphur burners can be retrofitted. Though for NOx (and particular gas-fired stations) these decrease thermal efficiency as they dial down the combustion temperature to reduce the nitrogen intake from the air (Martin et al., 2007). In the early 1990s National Power and Powergen retrofitted low NOx burners as originally planned by the CEGB. Most new CCGT plants also featured NOx control technology. According to Canning et al. (1999) this retrofit reduced NOx levels "upwards of 30%". The most prominent example of post-combustion abatement is Flue Gas Desulphurization (FGD) equipment which has been installed at several plants throughout the 1990s to cut SO_2 emissions which are responsible for acid rain. The program was initiated by the CEGB in 1986 on a "voluntary" basis. Actually, privatization led to a *reduction* in the number of plants that were fitted with FGD according to Reid and Longhurst (1990, p. 177).

A third source of emission reductions – and the focus of our analysis - is the increase in thermal efficiency (which in turn might be affected by fuel type and abatement technology). An increase in thermal efficiency will mostly be accompanied by an increase in environmental efficiency; NOx being the exemption. After privatization generators had strong incentives to improve commercial performance and thus increase thermal efficiency. However, it is less clear what the incentives for improved environmental performance were at

[10] Two important points are that different types of coal (i.e. hard coal and lignite) have different sulphur contents and as natural gas has its hydrogen sulphide content removed before distribution its sulphur dioxide emissions are negligible.

the plant level beyond emission limits and increases in thermal efficiency. Newbery (1995) provides some anecdotal evidence for incentives to increase environmental performance. He reports from a station visit that “environmental training [is] extensive and written into contracts for performance related pay”. Nevertheless, when making abatement decisions management might face trade-offs. For instance, though fitting a plant with FGD typically reduces emissions of SO2 by 90-95% the operation of FGD reduces thermal efficiency and thus increases fuel input and CO2 “input” as mentioned by Barrett and Protheroe (1995). Newbery (1995) notes that FGD can be bypassed, though emissions might be monitored. It is not clear what are the incentives to operate FGDs as their operation increases costs and might put plants at a competitive disadvantage (Newbery, 1995). Interestingly both the rise of CCGTs and the installation of FGDs might have increased emissions at other plants to the extent that regulatory constraints applied at the firm or industry level.

According to Adrain and Housley (1999) the industry outperformed its targets for SO2 and NOx emission by 32 percent in 1995. Also, the Electricity Association (1991) states that “the current programme of retrofitting coal-fired plant with low NOx burners will allow generators to meet the NOx emissions targets”. It seems that the “dash for gas” and the selective installation of abatement equipment were sufficient to fulfil (and surpass) existing environmental regulations which reduced the incentive to limit emissions at the plant level further.

We conclude the following. All three pollutants were reduced substantially during the 1990s where switching fuel at the industry level from coal to gas had the biggest impact. For NOx and SO2 the installation of abatement technologies at individual plants had an additional effect. Also, the substitution of foreign for domestic coal might have had an impact on SO2. Last, increasing competition led to an increase in thermal efficiency and thereby lower pollution. But unlike changes in the incentives for the use of traditional (and costly) inputs it is less obvious how privatization changed incentives for emissions reductions at the plant level beyond regulatory constraints. Therefore it is more difficult to distinguish different periods as in the previous section. We distinguish the periods before and after CCGT generation took off in 1994. Also around 1994 obligations to burn high-sulphur British coal expired. Another important year is 1998 when all CEGB planned FGDs had been installed (there have been no further FGD installation till the end of our sample). These three periods for emissions overlap with the periods for fuel and labour identified above; and we will use the same labels.

3 Literature

3.1 Theoretical evidence for the effect of changes in ownership and competition on performance

Whereas privatization implies a change in ownership, restructuring implies a change in industry structure, through horizontal or vertical unbundling and entry. The theoretical literature typically puts forward agency and property rights theories to understand the effects of privatization and restructuring on productive efficiency. A good summary of these theories in respect to privatization is provided by Megginson and Netter (2001) and Green and Haskel (2004).

Agency theory (see for instance Laffont and Tirole, 1993) opens up the neoclassical black box of the firm or the government. It recognizes the importance of asymmetric information and incentives under the separation of management and control for management behaviour. Management is considered intrinsically effort-averse (Fabrizio et al., 2007) which allows changes in ownership to produce better incentives and better control and subsequently better performance. Though it is asserted that private ownership implies stronger incentives due to the threats of takeover and bankruptcy, it is not obvious why government is unable to provide similar incentives and monitoring unless it has different objectives. Public choice theory asserts that economic welfare maximization is not the only government objective and that its other objectives might not necessarily support efficient production.

Zhang et al. (2005) summarize the theoretical arguments for why privatization should increase economic efficiency: privatization improves incentives for management due to a change in the allocation of property rights, the discipline introduced by capital markets, the introduction of more precise and measurable objectives, and the removal of political interference. Agency theory also recognizes the disciplining effect of competition. Fabrizio et al. (2007) suggest the following ways for competition to impose discipline on management: rewards for efficiency gains, threat of entry, and better control through reduction in agency costs. These and others are discussed in more detail by Nickell (1996). Though generally applicable to electricity generation the discipline that competition exerts could be less than in other – more contestable – markets.

When analysing privatizations several authors group the various effects predicted by these theories into three generic ones: management, privatization, and competition effect (in chronological order). Often management or management incentives change prior to privatization to prepare companies for sale or competition. At privatization management or management incentives might be improved further by the new owners. After privatization firms are typically exposed to competition which might increase pressure on management once more because now private owners are aided by the market (product and capital) for monitoring management. In reality these effects do not necessarily appear in chronological order. For instance, in the UK restructuring occurred both at privatization and again several years later.

3.2 Empirical evidence for the effect of changes in ownership and competition on performance

This section reviews the empirical evidence from UK privatizations in electricity and other industries as well as the evidence from US electricity restructuring. Although in the US the relevant change is not privatization, the experience is comparable as US restructuring typically implies vertical unbundling of generation accompanied by the introduction of wholesale and possibly retail competition. Since in the US restructuring occurs on a state-by-state basis many studies use difference-in-difference approaches allowing for a full counterfactual. Most UK studies – including the present one - assess the impact only in the time dimension producing potentially biased evidence. The empirical literature suggests several approaches to measure the impact on performance as discussed by Newbery and Pollitt (1997): financial performance, single factor productivity, total factor productivity (TFP), and full cost-benefit analysis. Each approach has its advantages and disadvantages as discussed by Green and Haskel (2004). For instance, often used measures of labour productivity do not recognize outsourcing and capital-labour substitution and capital investments after privatization lead to labour productivity improvements masking the effects of privatization.

3.2.1 Privatization studies

There is a sizable literature on the effects of UK privatizations. Most studies perform before/after comparisons of labour or total factor productivity. Pollitt (2000) and Green and Haskel (2004) provide reviews. Pollitt (2000) concludes that privatizations themselves are not associated with higher productivity growth or profitability. However, management changes prior to privatization improve performance. After privatization, only firms that experience tighter regulation or fiercer competition improve performance. Generally, effects are greater for financial as opposed to productivity measures. Newbery and Pollitt (1997) conduct a full cost-benefit analysis of restructuring and privatization against the counterfactual of the continued operation of the vertically integrated and publicly-owned CEGB. In particular, they find that fuel and non-fuel operating costs declined after privatization. However, Newbery (1998, p. 3) argues that it is unlikely that performance improvements are due to privatization itself. He observes that Nuclear Electric which was exposed to competition in 1990 but itself only privatized in 1996 experienced similar performance improvements as other generators. Pollitt (1997) finds a similar result for the privatization of the electricity industry in Northern Ireland. Newbery (1995) provides anecdotal evidence that after privatization there was a "change in culture of CEGB, where being base and max. thermal efficiency must change to value flexibility". It is not surprising that with restructuring commercial considerations became more important. Newbery's observation also implies that though plants have a greater incentive to minimize inputs for a given output, strategic dispatch nevertheless might lead to *lower* operating efficiency.

To summarize the evidence for UK privatizations (other than electricity) pre-privatization restructuring and management effects tend to be stronger than the privatization effect. And the latter is weaker than restructuring and competition effects after privatization as shown by for instance, Haskel and Szymanski (1992) using labour productivity. These findings might be biased because the data can mask the true effect of privatization. Even if privatization itself has a lower impact than competition it is likely to be necessary to bring about competition. Green and Haskel (2004, p. 65) state: "But to the extent that pre-privatization restructuring matters, the effect of privatization is rather subtle (and would not be picked up in conventional regression analysis of company performance)." Green and Haskel (2004, p. 105) summarize the literature on UK privatizations by saying: "Did privatization itself raise productivity? No. […] Did the process of privatization raise productivity? The answer is a resounding yes." There is also a literature on international comparisons. For instance, O'Mahony (1999) analyzes labour productivity in the gas, electricity and water industries for several countries including the UK. He finds no visible break in UK labour productivity for the period 1973-1990 (though there is a drop in 1984 which could be due to the miners' strike). But he shows a higher overall growth rate for the years after privatization.

3.2.2 US deregulation studies

We also consider the empirical evidence from the restructuring of the US electric industry. There are several important differences between the UK and the US. In the US there has never been a nationally integrated state-owned electric industry and therefore also no "big bang" UK-style privatization though there exist municipality owned distribution companies. A disadvantage of the US is that it can even be more difficult to locate the policy change as often it is the cumulative result of several decisions by both state and federal regulators as well as the courts.

A number of recent papers look at the effect of changes in regulation or restructuring on generation performance. Fabrizio et al. (2007) analyze the impact of ownership and competition on the efficiency of US electricity generation plants and find that investor-owned utilities in restructuring states reduced non-fuel expenses by up to 5 percent, labour input by 3 percent, and fuel input by up to 1.4 percent (though statistically insignificant) in comparison to firms in non-restructuring states. They use two counterfactuals: investor-owned utility (IOU) plants in non-restructuring states and municipality owned plants. They find that the gap with municipality owned utilities is larger than with IOU plants in non-restructuring states. This might imply either that IOU's in non-restructuring states are not a good control group because restructuring has spill-over effects or that the effect of ownership adds to the effect of competition. Note that the latter interpretation would contradict the general evidence from UK privatizations that ownership itself is not very important; as well as the findings of Pollitt (1995) and Arocena and Waddams Price (2002) who generally find no difference between ownership types for an international and Spanish sample respectively though Arocena and Waddams Price (2002) find that this is only true under price-cap as opposed to rate of return regulation. Hiebert (2002) uses Stochastic Frontier Analysis to investigate the determinants of cost efficiency for a sample of generation plants for the years 1988-1997. He finds that restructuring led to decreases in mean inefficiency for coal-fired but not gas-fired power plants and only finds mixed evidence for the effect of ownership.

3.2.3 Emissions

This chapter is primarily concerned with the effect of privatization and competition on emissions efficiency, but the analysis also includes the effect of emissions regulation on traditional efficiency. It is difficult to disentangle the two because in the UK privatization and environmental regulation coincide to some extent. And unlike for traditional inputs there is no coherent theory or empirical evidence on the effects of privatization, restructuring and competition on emissions.

Fowlie (2005) analyses the impact of US electricity market restructuring on emissions by investigating management compliance choices. She shows that in a competitive market management rather changes operation (e.g. shutting down, or switching fuel) than investing in abatement technologies as competition increases uncertainty and the cost of capital.[11] Given that capital intensive abatement solutions are more effective as shown by Fowlie (2005) the introduction of competition increases emissions. Thus, the same mechanism - the substitution of low capital cost technologies (i.e. CCGT) for high capital cost technologies – that led to an increase in fuel efficiency might have *decreased* environmental efficiency. We know for the UK that some CEGB planned FGDs were eventually not build which is evidence in support of this argument. However, as we do not have an adequate counterfactual we cannot test this hypothesis. Using past performance as the counterfactual is likely to be a bigger problem for non-traditional than for traditional inputs. Fowlie (1999) indentifies a second mechanism through which increased competition can lead to an increase in emissions: the "load-factor effect". Here competition leads sellers to adopt a pricing structure that increases off-peak demand (i.e. when load factors are calculated as average load divided by peak load-factors increase) and to the extent that coal provides base-load emissions increase. These arguments are based on the assumption that privatization and restructuring increase competition. Mansur (2007) on the other hand argues that restructuring might increase market power and thereby affect the output mix across plants. Now the impact on emissions depends on the technology of the competitive fringe. Following this argument UK privatization should lower industry emissions because competitive new entry typically relied on low-emissions gas. As for traditional inputs an important issue is competition. But unlike for traditional inputs competition can be good *or* bad for emissions depending on the technology. To some extent these arguments assume that emissions constraints are not binding which might be true for parts of the US where polluters can buy permits. Arocena and Waddams Price (2002) find

[11] The literature is inconclusive as to whether competition increases innovation. Whereas some find that competition increases technological change others find the opposite. See for instance Levin et al. (1987), Hannan and McDowell (1984), and Genesove (1999).

that in Spain emissions constraints were binding and when comparing public and private generators find that these constraints imply a higher cost for the latter in terms of forgone output. In the UK all the relevant instruments are command and control though as we argued above constraints might not be binding.

There are theoretical arguments that environmental regulation negatively affects traditional input efficiency. First, environmental regulation might hamper product market competition through cost increases and restrictions on competition (Heyes, 2009). And as we saw above competition feeds back to emissions. Second, several papers investigate the hypothesis that environmental regulation reduces efficiency for traditional inputs. Gollop and Roberts (1983) and Bernstein et al. (1990) for instance show that productivity and efficiency decreased with the introduction of sulphur emission controls in the US. However, Barla and Perelman (2005) find that for 12 OECD countries sulphur emission restrictions have no effect on efficiency at the country level. They believe that this is the case because any negative effects are off-set by technological change that results from implementing the emission restrictions.

To summarize, the literature provides evidence for a positive effect of privatization and competition on firm performance at least for traditional inputs. For non-traditional inputs the effect could be either way. Most authors agree that the biggest effects on traditional inputs are associated with changes in management incentives or competition irrespective of the actual change of ownership.

4 Hypotheses

For our hypotheses we will again distinguish the privatization (1990-1994), restructuring (1995-1998), and competition (1999-) periods as discussed above. The literature on privatization and restructuring acknowledges possible anticipatory effects in particular due to the change of management or management incentives before actual privatization. However, for the UK ESI we are not aware of any changes in management or management incentives before privatization. Our first hypothesis therefore is:

Hypothesis 1: there is no break in the efficiency for any of the inputs before privatization.

The literature on the effects of privatization concludes that privatization is necessary but not sufficient for significant performance improvements. This also seems to be the case here as privatization was followed several years later by a reduction of political interference in fuel choice, changes in market structure, and changes in trading regimes. However, management was free to shed labour at privatization. Therefore our second hypothesis is:

Hypothesis 2: there is no break associated with an efficiency increase for any of the inputs during the privatization period except for labour.

Political interference decreased and competition developed in the second half of the 1990s when incumbents were forced to divest generation plants to competitors in 1996, retail competition started in 1998, and US firms entered the market around the same time. Assuming that labour had been reduced to efficient levels before our third hypothesis is:

Hypothesis 3: there is a break associated with an efficiency increase for fuel during the restructuring period.

Last we turn to the three pollutants. All pollutants and especially CO2 for which there is no abatement technology are closely related to fuel use. The same is true for SO2 and NOx once we control for abatement technologies. Therefore, and despite of not controlling for NOx abatement technology other than through plant-epoch fixed effects our fourth hypothesis is:

Hypothesis 4: there are no breaks for CO2, SO2, and NOx independently of any breaks in fuel efficiency.

And the relation between fuel efficiency and emissions efficiency should be positive for CO2 and SO2 but negative for NOx at least for gas-fired stations.

5 Empirical Model

Our model has three main characteristics: the generation technology, efficiency, and the structural breaks in efficiency. As usual efficiency is a function of the technology. Following Fabrizio et al. (2007) we derive plant-level factor demands from a behavioural model constraint by the technology. This model is somewhat different from a standard production model and has the advantage of being better suited to the input substitution patterns in electricity generation. It has the practical advantage of allowing us to estimate single factor demand functions without being constraint to a single factor efficiency measure. Also, individual demand functions allow different inputs to be affected by policy changes at different points in time. And we maximize the number of observations for each input as our data is highly unbalanced with gaps.[12]

Fabrizio et al. (2007) start with the observation that a standard Cobb-Douglas production function where output is a function of current inputs is not a good representation of the short-run production decision at the plant level. They distinguish between "probable" and "actual" output. Observed or actual output could be more or less than planned output because actual demand differs from expected demand or because of unexpected changes in plant availability. Actual output is modelled as a Leontief production function of probable output and fuel input. Probable output is a function of capital which is embedded in the constant, labour, and materials. Thus, whereas non-fuel inputs are determined before production takes place fuel varies with actual production. The key feature of the model is that "actual" output equals "probable" output multiplied by a shock that is observed by the plant managers but not by the researcher. This Leontief production function allows for the medium-run substitution between material and labour but does not allow either to substitute for fuel in the short run. Also, in the short run capital cannot be substituted for and therefore is embedded in plant fixed effects. We slightly modify the original model and include non-traditional inputs in the same way as traditional inputs. Equation (1.1) gives actual output:

$$Q_{it}^{A} = \min\begin{bmatrix} g\left(E_{it},\Gamma^{E},\varepsilon_{it}^{E}\right), f\left(C_{it},\Gamma^{C},\varepsilon_{it}^{C}\right), h\left(S_{it},\Gamma^{S},\varepsilon_{it}^{S}\right), q\left(X_{it},\Gamma^{X},\varepsilon_{it}^{X}\right), \\ ,Q_{it}^{P}\left(K_{i},L_{it},M_{it},\Gamma^{P},\varepsilon_{it}^{P}\right)\exp\left(\varepsilon_{it}^{A}\right) \end{bmatrix} \quad (1.1)$$

where Q^{A} and Q^{P} stand for actual and probable output respectively and $Q_{it}^{A} = Q_{it}^{P} * \exp\left(\varepsilon_{it}^{A}\right)$. K, L, M, and E denote capital, labour, materials, and fuel input. C, S, and, X represent CO2, SO2, and NOx emissions. The reason for adding non-traditional inputs in this fashion is that they are a function of fuel input and therefore are not decided upon before production takes place. Moreover, plant-level emission limits might constrain production especially in the case that abatement technology fails. Γ denotes the coefficient vectors and ε represents standard error terms.

[12] When using a production function one could allow breaks associated with each individual input which should produce similar results.

In order to derive factor demands for labour and materials the model assumes cost-minimization behaviour constraint by a Cobb-Douglas production function where probable output is a function of capital, labour, and materials. Capital is not an input into the cost minimization problem because it is assumed fixed in the short run. The assumption of cost-minimization might be restrictive as it is likely that the CEGB (and possibly the privatized plants) did neither maximize productive nor allocative efficiency. Also the focus on the short run might underestimate the benefits of privatization as Arocena and Waddams Price (2002) find that private generators have a higher allocative efficiency in the long run. See Fabrizio et al. (2007) for the details of this derivation. The resulting labour demand equation is:

$$\log(L_{it}) = \beta_1^L \log(Q_{it}^A) + \beta_2^L \log(W_{it}) + \alpha_i^L + \varepsilon_{it}^A \tag{1.2}$$

Where labour is a function of actual output, capital (embedded in the constant) and the wage. Due to a lack of data we do not derive a demand for materials. Unlike for labour and materials fuel input does not depend on price. Its price only enters indirectly through the output the plant is dispatched to produce as the fuel price affects the merit order. Assuming that $g(\cdot)$ is monotonically increasing inversion produces the following fuel demand equation:

$$\log(E_{it}) = \beta_i^E \log(Q_{it}^A) + \alpha_i^E + \varepsilon_{it}^E \tag{1.3}$$

The same reasoning leads to the demand functions for CO2, SO2, and NOx:

$$\log(C_{it}) = \beta_i^C \log(Q_{it}^A) + \alpha_i^C + \varepsilon_{it}^C \tag{1.4}$$
$$\log(S_{it}) = \beta_i^S \log(Q_{it}^A) + \alpha_i^S + \varepsilon_{it}^S \tag{1.5}$$
$$\log(X_{it}) = \beta_i^X \log(Q_{it}^A) + \alpha_i^X + \varepsilon_{it}^X \tag{1.6}$$

5.1 Identification

Unlike Fabrizio et al. (2007) we have no cross-sectional control group as all UK thermal plants were privatized in 1990 (or shortly thereafter in Scotland in 1991 and Northern Ireland in 1992). We identify the impact of privatization and competition as structural breaks across time. Our counterfactual is a plant’s own past performance. A weakness of this approach is that we cannot distinguish between the impact of the natural experiment(s) and other changes in time like changes in ownership after privatization. Waddams Price and Weyman-Jones

(1996) regress an efficiency score on a regime dummy and a trend interpreting the later as underlying technical change and therefore part of the counterfactual.

Building on our theoretical model above (equations 1.1 to 1.6) we introduce a generic input demand equation where input N (Fuel, Labour, CO2, SO2, NOx) for firm *i* in year *t* and regime *r* is a function of output (NET MWH), input price (PRICE), an indicator for the presence of FGD plant (FGD), a variable measuring the vintage of the plant (AGE), plant-epoch fixed effects (α_i^N), a trend (t), and a regime constant (POST) that switches on after a given year. Plant-epoch effects represent a given plant for the period where its capacity does not change. Depending on how often its capacity changes a plant is associated with several plant-epoch effects. Note that the FGD indicator captures the presence but not necessarily the operation of the FGD. We opt to include a trend instead of year-fixed effects because the latter absorb all the variation across regimes and thus produce constant values for the break test statistic.

$$\begin{aligned}\log(N_{irt}) &= \beta_1^N \log(NET\ MWH_{irt}) + \beta_2^N \log(PRICE_{irt}^N) + \beta_3^N \log(FGD_{irt}) + \beta_4^N AGE_{irt} \\ &+ \beta_5^N POST_{irt} + \alpha_i^N + t^N + \varepsilon_{irt}^N\end{aligned} \quad (1.7)$$

The regime constant allows for different average input usage for given output between regimes, i.e. the periods before and after the break. Thus, the intercept change is common for all plants and the regime constant can vary with the sample composition in spite of the inclusion of fixed effects. Alternatively one could allow each plant to break at a different date (or not at all). One issue here is that such an approach would not allow for plant-epoch effects as it requires plant-fixed effects. For fuel and the non-traditional input demands we drop the terms including price following our theoretical model above. And for labour we observe the wage at the regional instead of plant level. This is a partial change model as we do not allow all coefficients to change with the regime. The implicit Null for all hypotheses is $\beta_5^N = 0$.

We include a variable for age because an important determinant of a plant's efficiency is its vintage according to Bantock and Longhurst (1995). Joskow and Schmalensee (1987) find that plant performance "deteriorates significantly" with age. There seems to be a trade-off between thermal efficiency and reliability (companies retreat from the technological frontier but in-house engineering and design leads to better performance). However, Hiebert (2002) states that length of service might actually increase performance as local management learns to better operate the plant. Pollitt (1995, p. 132) finds no significant age effect for a sample of base load plants. The trend variable should pick up exogenous changes in technology. There remain potentially important factors that we cannot control for like an individual plant's rank in the merit order. After privatization different plants might have been called on, peaking plants might be different, which would affect average performance as discussed by Knittel (2002).

For each demand equation we model a single, abrupt, and known or unknown break. The model is restricted in these ways for the following reasons. Though the actual break might be gradual to model the break as abrupt is more parsimonious and allows for formal inference. The assumption of a single break could be relaxed. Bai (1997) proposes an iterative procedure where first a break is identified, then the sample split at the break, and each sub-sample is tested for a break. But as our sample is rather short we do not do this here. Unlike many previous studies we do not assume that the break dates are known. The reason is that even though the dates for the various regulatory changes are known there is no theoretical guidance as to when exactly the impact occurs as discussed above.

The literature distinguishes between testing for structural breaks and estimating a particular break date. We follow this distinction and use a standard F-test to test for structural breaks and the global minimum of the sum of squared residuals (SSR) of the unrestricted model (i.e. allowing for breaks) as an estimate for the break date (Bai, 1994). The F-test is based on the general idea that when the break point is unknown and the error variance is the same across the two regimes one should select the break point which corresponds to the smallest total sum of squared residuals (or the highest F-statistic) (Kennedy, 2003, p. 113). The maximum F and the minimum SSR coincide only if the errors are homoskedatic. Moreover, Hansen (1997) suggests that local minima of the SSR can be viewed "cautiously" as estimates of multiple breaks. If the break date is known the F-statistic (Chow-statistic) is a good statistic when testing for a structural break. However, if the break date is unknown a better statistic is the maximum F-statistic (Quandt-statistic) for a sequence of Chow-statistics over a window of candidate break dates (Quandt, 1960). Hansen (2001) explains that the Quandt statistic is to be preferred because using the Chow-statistic similar break dates (i.e. adjacent years) can produce different results. The critical values for the Chow-statistic and the Quandt statistic differ. If the break date is known the test statistic follows a chi-square distribution if not it follows a non-standard distribution derived and tabulated by Andrews (1993) and Andrews

(2003)[13]. The Andrews critical values tend to be twice as high as the values of the chi-squared distribution. Intuitively, the test is more "demanding" because the break is unknown. Our window for candidate break dates is 1985-2002 which implies a trim factor of about 0.15 for the Andrews critical values. This window opens several years before privatization and closes two years after NETA.

Another issue for identification is that supply is likely to be endogenous because it is correlated with shocks. For instance a production failure would reduce output and fuel input simultaneously. Fabrizio et al. (2007) tackle this issue using state-level demand as an instrument for supply. But even though endogeneity biases the coefficient estimates it does not bias the test for structural change according to Perron and Yamamoto (2008). Actually break tests based on instrumental variable (IV) regressors are less precise than tests based on standard OLS regressors. One reason for this result is that the generated IV regressors have less quadratic variation than the original regressors. We use robust OLS estimators to test for structural breaks and a robust generalized method of moments instrumental variable estimator (GMMIV) to estimate the coefficients associated with the breaks. The instruments for supply are the plant's fuel type and the total supply by CCGT and nuclear plants. All three instruments should be uncorrelated with shocks to plant availability. But at the same time the instruments reflect a plant's position in the merit order and therefore are correlated with supply. Using these instruments we find that supply is endogenous. Last there is attrition. The entry and exit of plants might be important for our results because different plant types react differently to changes in ownership and competition. For instance, firms might decide to improve performance only at specific plants in response to policy changes. This is important because our regime dummy captures the *average* effect across plants. In order to see how the industry-level plant mix affects our results we alternatively restrict our full sample to plants that are observed for at least 19 out of 25 years. Effectively the restricted sample consists of coal-fired stations that we observe both before and after privatization. The data, variables and samples are described in more detail in the next section.

[13] The critical values are tabulated by p, the number of coefficients that are allowed to change and π, the trim factor. A trim factor is expressed as a fraction between 0 and 1 and gives the interval $[\pi, 1-\pi]$ of the sample over which breaks are allowed to occur. Thus if the sample is of length 10 $\pi=0.2$ implies that the window for candidate breaks is observations 2 to 8.

6 Data and Summary Statistics

Several people have compiled the data set over several years. Besides firm and industry publication we also obtained data from several companies directly. Our full sample includes conventional thermal plants, CCGT plants, and a few CHP plants. Nuclear and renewable plants are excluded because for non-thermal generators the measurement of fuel input is not straight forward. Also, they do not produce the same pollutants as thermal plants.[14] Due to its patch work collection the data has several shortcomings. We know (or suspect) that sometimes different sources define the variables in different ways. For instance, whereas some data is based on financial years other data is based on calendar years. We correct for this by constructing calendar year data from the weighted financial year data (weights are simply the number of months). There are large gaps in our data. Figure 2 and Figure 3 illustrate these gaps for the supply variable (i.e. electricity output) for the full and restricted samples respectively. It gives the count of identified observations by year and fuel in the upper panel and the count of observations for which supply is not missing in the lower panel.

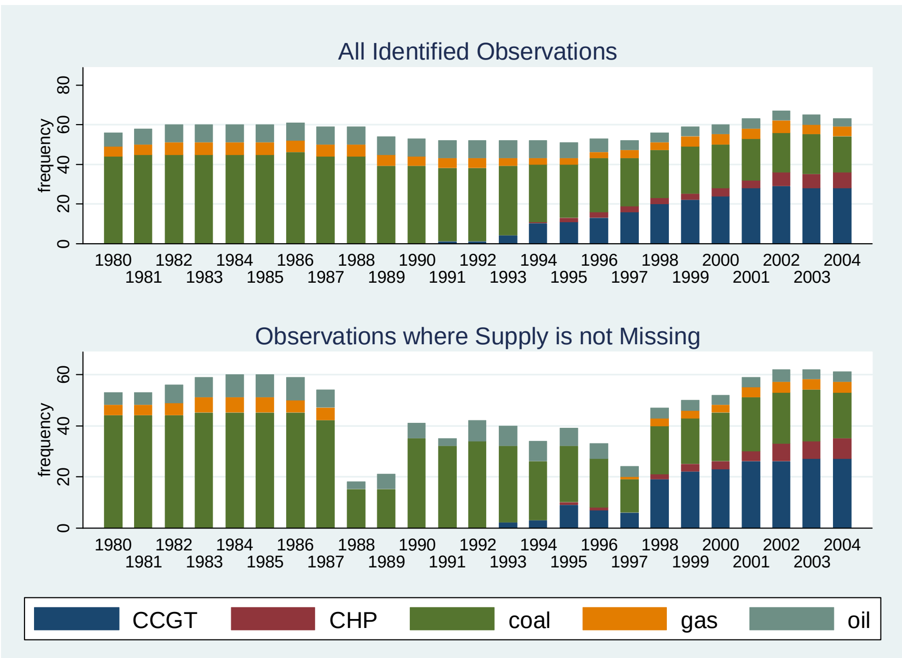

Figure 2: Count of Observations by Year (Full Sample)

[14] This point is also discussed by Pollitt (1995, p. 26, endnote 3).

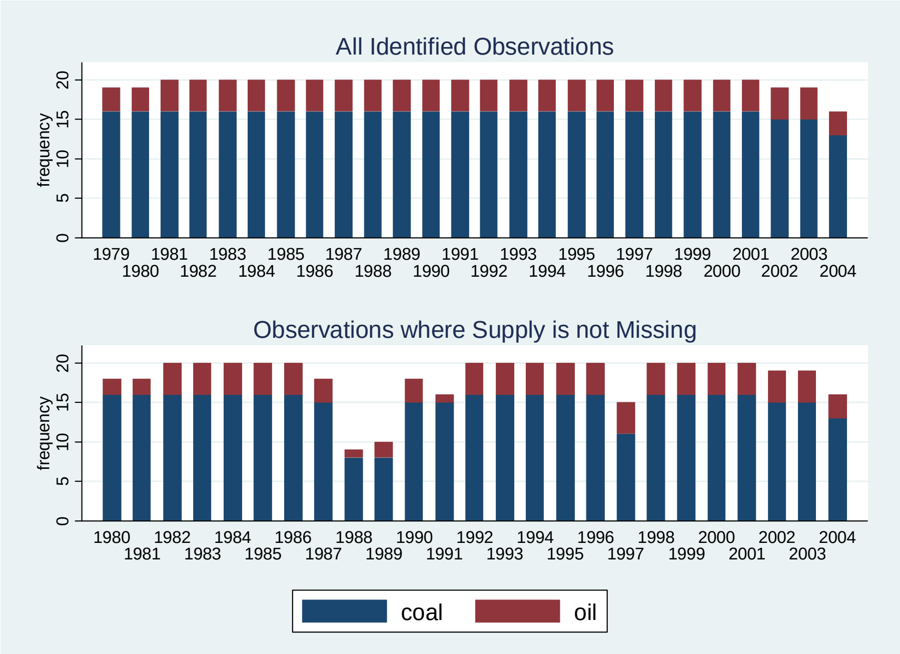

Figure 3: Count of Observations by Year (Restricted Sample)

For the full sample it is interesting to see that absent any reporting obligations starting just before privatization it is much more difficult to obtain the data. But this trend seems reversed in the late 1990s possibly due to mandatory environmental reporting and possibly the industry reached a new equilibrium where non-reporting conferred no competitive advantage any longer. Therefore we cannot say that the missing values are entirely random in the time-series. But we have no reason to believe that the same is true for the cross-section. For the restricted sample there are much fewer gaps throughout the 1990s. Note that the drop in the number of observations towards the end of the samples is likely to be due to closure of older coal-fired stations. The two figures also allow us to compare the plant mix across the two samples. Whereas all plant types are included in the full sample only coal and oil plants are included in the restricted sample.

In order to minimise the number of gaps we derived missing observation where possible. For instance, missing observations for CO2 emissions were derived from supply. The appendix gives more detail on these calculations. Though filling gaps this way may introduce some bias we believe it is better than having an even larger number of missing observations. One potential bias we are aware of is the derivation of CO2 before privatization. Since there is virtually no data available on emissions before privatization we derived CO2 from supply for these years. The result is that fuel and CO2 efficiency in our sample (see Figure 4) are more closely related than it is likely to be actually the case. We believe that plants as well derive emissions from fuel input for reporting purposes. For SO2 and NOx we did not attempt to fill the missing values before privatization because the relationship between fuel and emissions is less straightforward. All the variables and their measurements are summarized in Table 3.

Table 3: Variables and Measurement

Variable	Definition
	Dependent variables
Fuel	log (Mtce/year)
Labour	log (number of employees/year)
CO2	log (kt CO_2 /year)
SO2	log (kt SO_2 /year)
NOx	log (kt NO_x /year)
	Independent variables
Supply (NET MWH)	log (net GWh/year)
Capacity	log (net MW)
FGD	1 if FGD fitted; 0 otherwise
Age	number of years since first unit commissioned
Trend	time trend
Wage	log (regional wage, index)
POST	structural break indicator: 1 if year >= year of break; 0 otherwise

Table 4 gives summary statistics. Note that due to the gaps in the data the number of observations varies greatly between the different variables. Overall the data set covers the years 1980 to 2004 except for SO2 and NOx. For these two pollutants our data set only starts in 1988 slightly weakening our results as effectively we are not able to investigate breaks before or at privatization but only afterwards. When comparing the full and restricted samples we see that the number of observations is more than halved. Mean values for fuel input, supply, and capacity are much higher indicating that the restricted sample contains much larger plants. Also, the mean value for age for the restricted sample is double that of the full sample.

Table 4: Summary Statistics

Variable	Full Sample					Restricted Sample				
	Obs.	Mean	St. Dev.	Min.	Max.	Obs.	Mean	St. Dev.	Min.	Max.
Fuel	1149	1.532	1.702	0.001	11.038	456	2.657	2.066	0.003	11.038
Labour	445	272.249	235.016	1.000	1130.000	217	428.871	243.130	41.000	1130.000
CO2	1176	3235.121	3827.232	1.488	25100.000	466	5935.283	4647.307	5.630	25100.000
SO2	533	31.888	46.784	0.000	269.300	245	59.414	55.591	0.243	269.300
NOx	615	9.132	13.401	0.000	87.979	245	18.200	16.493	0.090	87.979
Supply	1175	4068.328	4538.680	1.000	29000.000	456	6854.263	5550.595	5.375	29000.000
Capacity	1493	886.730	778.557	31.000	3960.000	523	1547.373	826.227	120.000	3960.000
Load factor	1155	45.121	29.268	0.151	176.574	452	46.279	24.755	0.151	104.967
Wage	1437	272.327	92.844	99.271	474.250	493	267.790	87.191	101.500	466.711
Age	1438	18.525	11.011	0.000	47.000	514	22.767	9.288	0.000	47.000

Table 5 gives the correlation matrix for the full sample. We do not report the correlations for the restricted sample as they are fairly similar. All the inputs are positively correlated with supply and capacity. Naturally, these correlations are the lowest for labour. One interesting observation is that all inputs are positively correlated with the age but negatively correlated with the trend suggesting that they contain different information and should both be included in the model.

Table 5: Pearson Correlations (Full Sample)

		1	2	3	4	5	6	7	8	9	10	11
Fuel	1	1										
Labour	2	0.68	1									
CO2	3	0.99	0.73	1								
SO2	4	0.81	0.80	0.85	1							
NOx	5	0.91	0.82	0.94	0.91	1						
Supply	6	0.98	0.59	0.94	0.73	0.84	1					
Capacity	7	0.77	0.55	0.77	0.60	0.67	0.74	1				
Load factor	8	0.39	0.03	0.33	0.21	0.26	0.48	-0.02	1			
Wage	9	-0.12	-0.63	-0.18	-0.42	-0.35	-0.04	-0.10	0.29	1		
Age	10	0.10	0.31	0.18	0.22	0.23	-0.03	0.09	-0.42	-0.19	1	
Year	11	-0.10	-0.59	-0.15	-0.41	-0.32	-0.03	-0.06	0.26	0.98	-0.15	1

Next we plot indices for input efficiencies on a log scale (so that lines of constant slope have a constant growth rate) for the full sample in Figure 4. These indices are cross-sectional averages indexed on the year of privatization, 1990. Labour efficiency decreases till privatization and increases dramatically thereafter. Fuel, CO2, SO2, and NOx efficiencies are virtually unchanged till about 1992 when they start increasing. For fuel and CO2 this upward trend stops in 2000, which is likely due to the moratorium on new gas-fired generation and a subsequent increase in coal burn. There is no visual evidence for a clear structural break around privatization in 1990 except possibly for labour. For the restricted sample (not shown) the picture is similar though efficiencies increase by less.

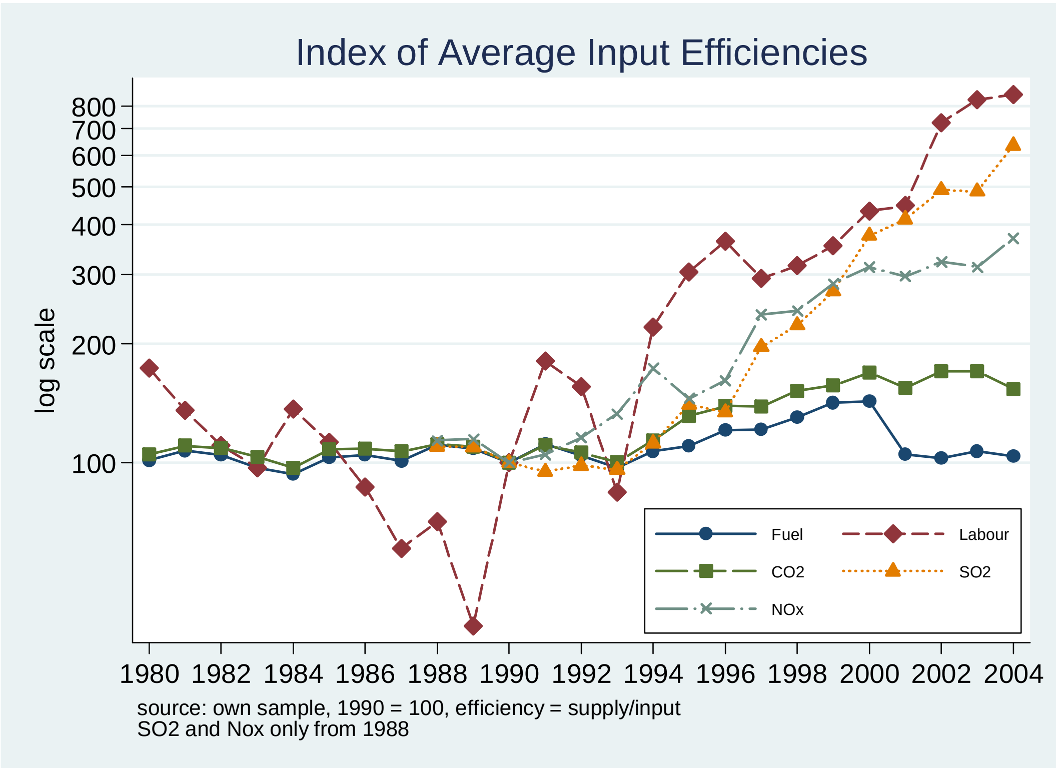

Figure 4: Index of Average Input Efficiencies

7 Results

Results are presented by demand equation and sample. They distinguish between the break date meaning the year where a break occurs and the corresponding intercept coefficient which gives the level change in efficiency. Table 6 gives the years and intercept coefficients for the statistically significant break dates for the full and restricted samples. Remember that whereas the full sample includes all fossil fuel plants the restricted sample essentially consists of coal-fired stations only.

In Table 6 the first column gives the inputs where every first row is for the full sample and every second row for the restricted sample. The second column gives the primary break dates (the global minimum for the SSR). The third and fourth columns give additional (tentative) break dates (up to two and in increasing order of the SSR). The econometric significance of the break dates depends on whether the F-statistic is higher than the Chi-squared or Andrews critical value for known or unknown breaks respectively. Both tests have a size of 5%. All primary break dates except for fuel for the full sample are statistically significant at the Andrews critical value. For the full sample for fuel the F-statistic stays just below the critical value for an unknown break. Strictly speaking when searching for a break using the full sample the data does not reject the null hypothesis that there is no break. The last three columns give the coefficients (expressed in percent) associated with these break dates. A negative coefficient sign implies that input efficiency *increases* meaning that after the break plants on average use less input for a given supply. Note that not all coefficient signs are negative and several break dates are associated with *decreasing* efficiency. It seems that results differ more across inputs than across samples.

Next, Figure 5 plots the same percentage changes associated with the intercept coefficients against the candidate break dates for all break dates irrespective of the breaks statistical significance. For instance, the first row in Table 6 shows that for fuel efficiency for the full sample the break occurs in 1996 and is associated with an efficiency increase of 5.6 percent which means that for a given output 5.6 percent less inputs are needed for the years after 1996 as compared to the years before. The same 5.6 percent can be read from the left panel of Figure 5 for the line with the round dots. The results in Table 6 and Figure 5 are extracted from Figure 6 to Figure 10 and Table 7 in the appendices which provide all results. Figure 6 to Figure 10 plot the SSR (right y-axis) and F-statistics (left y-axis). The dashed lines give the Chi-squared and the dotted lines the Andrews critical values respectively.

Table 6: Summary of Break Dates and Coefficients

Input (1st row full/2nd row restricted sample)	Break dates (min. SSR)			Intercept change at break dates (%)		
	Global	Local 1	Local 2	Global	Local 1	Local 2
Fuel	1996'	1990'		-5.60*	8.11**	
	1996"	1990"	1999"	-4.88**	11.20***	-5.93*
Labour	1992"	2001"		-30.39***	18.73**	
	1992"	1994"	1999"	-23.06***	-23.91***	34.02***
CO2	1990"	1995'		7.19***	-4.03	
	1990"	2000'	1995"	6.52*	-5.31	0.63
SO2	1994"	2000"		48.28**	-22.55*	
	1991"	2001"		52.98***	-25.78***	
NOx	1993"	1996'	2001'	-23.03***	-14.35**	13.00***
	1996"			-4.79		

' F > 5% Andrews, ' F > 5% Chi-squared

Robust p-values: *** p<0.01, ** p<0.05, * p<0.1

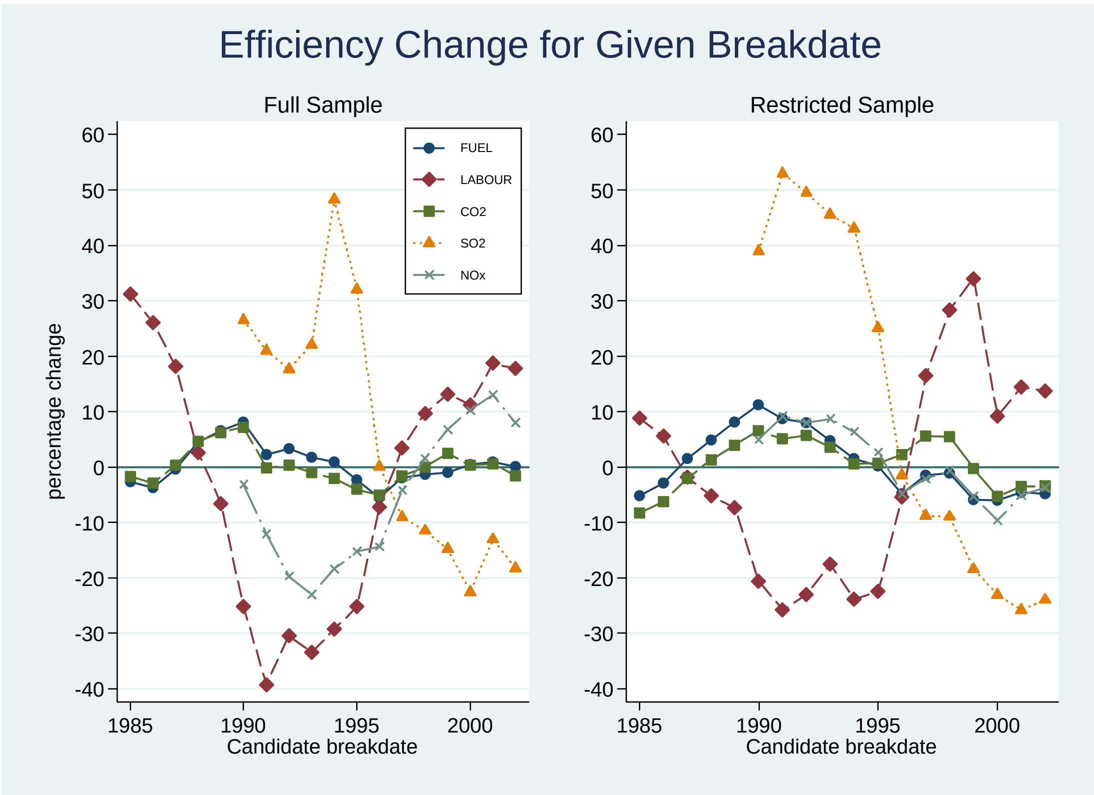

Figure 5: Efficiency Change for Given Break Date

During the privatization period (1990-1994) we find a primary break for labour corresponding to an efficiency increase of about 30 percent. Figure 7 in the appendices shows that the test statistic for the full sample (upper panel) drops sharply in 1989 and reaches a minimum in 1992 suggesting that labour reductions started just before privatization. The break date is the same for both samples though the efficiency increase is lower for the restricted sample (compare the panels in Figure 5) which might be due to the fact that CCGT plants generally require less labour and therefore the true effect of privatization is overestimated for the full sample. This is true even though our model accounts for fixed effects because our regime dummy picks up the average change across plants which might change with the composition of the sample. For fuel we only find a secondary break in this period which surprisingly is associated with an 8.1 percent *decrease* in efficiency. There is only a small difference between the two samples. One possible explanation for this result is decreasing load factors at privatization possibly driven by market power. Another explanation might be political pressure to burn inefficiently large amounts of British coal. We find primary breaks for all three pollutants though only the break for NOx is associated with an efficiency increase. As CO2 and fuel are highly correlated the break for CO2 occurs in the same year as a break for fuel and both have similar quantitative impacts. The breaks for SO2 occur in 1994 and 1991 for the full and restricted samples respectively and are associated with about a 50 percent decrease in efficiency. The break for the full sample occurs at about the time when CCGT generation starts to increase dramatically and when the first FGD is installed at Ratcliffe. As we control for FGD and plant-fixed effects the efficiency decrease might capture the effect FGDs and CCGTs had on other plants by loosening their emission constraints. As emission limits typically operate at the firm or industry level it is possible that once FGDs and CCGTs operate other plants are free to emit more. Though it is not obvious why the break for the restricted samples occurs several years earlier. For NOx the break occurs in 1993 shortly after privatization and just when CCGT generation takes off. It is associated with an efficiency increase of about 23 percent. Comparing the two samples it is possible that the inclusion of CCGT plants explains the break in 1993 for the full sample as these were generally fitted with low-NOx burners, which is not captured by the fixed effects if operation of such equipment varies across time as suggested by Martin et al. (2007) for the US.

The restructuring period (1995 to 1998) sees the primary break for fuel in 1996 the year when the two incumbents were mandated to divest generation assets to competitors. This break is associated with an efficiency increase of about 5 percent for both samples which is interesting because it indicates that the effect is the same for various types of plants. Again there is a comparable break for CO2 in the same year. There is no further break for labour in this period. There is a secondary break for NOx, again associated with an increase in efficiency. As we do not control for the fitting of NOx abatement technology this might explain both efficiency increases. However, individually the increases fall short of the expected 30 percent (see p. 20).

During the competition period (1999-) no primary breaks occur. For fuel a second local minimum in 1999 is only observed for the restricted sample suggesting that increased competition in the late 1990s mostly affected coal-fired plants. And even though these plants are also included in the full sample the effect might be masked. Also, for labour there is a secondary break associated with a decrease in efficiency. This result confirms anecdotal evidence that right after privatization labour was reduced to an extent that might have compromised operational safety forcing an increase in staff levels during the late 1990s. There is a more pronounced dip in 1999 for the restricted sample suggesting that is was mostly at older coal-fired plants were the initial lay-offs were reversed. Next, there is a second and third break for SO2 and NOx respectively. Whereas SO2 efficiency increases it decreases for NOx. For SO2 the drop in emissions of about 20 percent might capture the effect of older plant retiring or coal-fired plants switched to less sulphur rich coal. That the effect is larger for the restricted sample supports this explanation. Again the installation of FGD should not affect the results for SO2. Though for the FGD plants the FGD and regime indicators are correlated and it is not clear whether the overall effect is correctly attributed. For NOx the efficiency decrease in 2001 occurs shortly after the overall amount of coal burn increased again in 1999 due to a moratorium on gas fired plant. The increase in NOx emissions might also be explained by stronger competition leading plants to trade-off higher NOx emissions for more output. That the break coefficients for fuel and NOx have the opposite signs for this period is clearly shown in the left panel of Figure 5. But we do not observe this for the right panel confirming that the trade-off between fuel and NOx efficiency mostly exits for gas-fired stations which are not included in the restricted sample.

8 Discussion and Conclusion

We find evidence that privatization and subsequent changes in regulation and market structure had a significant positive impact on plant-level efficiencies for traditional and non-traditional inputs over the decade 1990 to 2000. However, not all the efficiency changes were always positive.

Generally, the positive effects we observe are much stronger than the effects reported by for instance Fabrizio et al. (2007). Whereas they find no significant effect of US restructuring on fuel efficiency we find efficiency increases up to 5 percent. For labour they find effects up to 3 percent where we find effects up to 30 percent! We believe that this is due to the different contexts. In the US most plants have always been privately owned and regulated. Restructuring should have a lower impact than the more radical changes in ownership and regulation that took place in the UK. The difference also highlights that the inefficiencies that public ownership accumulated in the UK were much higher than the inefficiencies that rate of return regulation accumulated in the US.[15]

Now we discuss our four hypotheses. We find evidence in support of our first hypothesis that there is no break in any of the inputs before privatization. There are several reasons why performance did not improve in anticipation of privatization. Only in 1988 was it certain that privatization would go ahead. And, at the time it was obvious to the players that full competition would not materialize for at least a couple of years after privatization. This result is markedly different from earlier UK privatizations where performance often improved in anticipation of privatization. For instance, Waddams Price and Weyman-Jones (1996) find structural breaks for the efficiency of British Gas several years before privatization. Nevertheless, they find the strongest evidence for a break at the date of privatization. The same is true for electricity restructuring in the US where Fabrizio et al. (2007) show that efficiency improvements occur in anticipation of restructuring. But unlike for other UK privatizations for electricity labour productivity only increased at privatization.

Our results provide evidence in favour of our second hypothesis that there is no break associated with an efficiency increase for any of the inputs during the privatization period except for labour. This is not surprising. We know that the CEGB was probably overstaffed

[15] The argument that rate of return regulated firms over-invest goes back to Averch and Johnson (1962) though empirical studies were not able to prove the effect conclusively.

and electricity workers had less bargaining power than miners or the new shareholders. But there were no involuntary lay-off and it seems that redundancy packages might have transferred some of the rents from privatization to employees. Also, the quantitative result is likely to overestimate the true effect on employment as we do not account for outsourcing after privatization. Unexpectedly we also find a secondary break for fuel. However, as the break is associated with a decrease in efficiency it provides no evidence against our hypothesis.

We find evidence in support of our third hypothesis that there is a break associated with an efficiency increase for fuel during the restructuring period. The break occurs in 1996 the year when market concentration fell because the two incumbents were forced to divest plants to competitors. This result is in line with the theoretical and empirical literatures both suggesting that competition is much more important for performance than ownership. What is more striking (and worrying for shareholders) is that this implies that generators failed to minimize cost instead of just failing to pass on cost savings to customers supporting Hicks (1935) "quiet life" hypothesis. The result also underlines the danger of using financial performance indicators which can mask underlying technical performance.

We find mixed evidence for our fourth hypothesis that there is no break for CO2, SO2, and NOx independently of any breaks in fuel efficiency. The breaks for CO2 are almost the same as for fuel which is not surprising as the two are highly correlated due to the absence of any abatement technologies for CO2. On the other hand the breaks for SO2 and NOx are mostly independent of the breaks for fuel. Breaks for these emissions are likely to relate to abatement effort that we do not model (i.e. other than the installation of FGD). Such efforts include installation of abatement technology, burning of different coal type, and operational change. What is maybe the most interesting result is that once we account for fuel switching at the industry level and the installation of FGDs we actually observe efficiency decreases for emissions in some cases. Large reductions of emissions at some plant might allow higher emissions at other plants as long as plant-level caps are not binding.

Our approach has several shortcomings. First, we are aware that there are several measurement inconsistencies as well as gaps in the data which we tried to overcome. Second, the data provides no counterfactual except for firms' own past performances. But even if a control group was available constructing a counterfactual would not be straight forward because certain changes like the installation of abatement technology were planned before privatization but only installed afterwards (and the announcement of privatization might have changed these plans). Third, the empirical model assumes that there is a common, single, and abrupt break in each input demand equation. Looking at our descriptive statistics it seems that some efficiencies are more likely to exhibit a gradual shift.

On the other hand our approach has certain strengths. We have compiled a new plant-level panel data set that spans about ten years before and after privatization which allows for a more robust analysis of the events around privatization. Instead of financial indicators we use productivity as performance measure which gives a more realistic picture. Using efficiency based on physical data might be one reason why our results differ from the results of studies of other UK privatizations (Pollitt, 1995, p. 26). In particular, other industries showed performance improvements in anticipation of privatization. We also include emissions as non-traditional inputs though we only have shorter and incomplete series for emissions at the plant level. The main advantage of our model is that we do not presuppose that breaks take place at any particular date or that breaks are common for different inputs.

As plant fixed effects do not sufficiently control for unobserved heterogeneity and efficiency changes might not be the same across plant types we use two different samples. Fixed effects do not capture changes in the merit order and associated changes in operation as well as abatement efforts other than FGD. Secondly, we only account for the average efficiency impact of breaks across plant-types. As our results somewhat differ across the two sample we believe that plant-level time-variant factors are important and that efficiency changes vary across plants.

Also we allow for inference for known or unknown breaks. This distinction might seem philosophical but stresses that if we do not know the potential break date in advance more evidence is required to infer that there is a break. Our results are mostly strong enough to infer an unknown break. The exception is fuel where for the full sample the test statistic just fails to clear the hurdle for an unknown break.

We conclude that electricity privatization like most other UK privatization was a unique experience. Privatization itself in spite of strong market power led to a dramatic increase in labour productivity. On the other hand for fuel and emissions efficiency privatization might have been necessary but certainly not sufficient to bring about improvement. Aggregate emission limits might have lead to emission increases at individual plants in response to abatement efforts elsewhere which might be efficient as long as the aggregate caps are effective.

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Appendices

Results

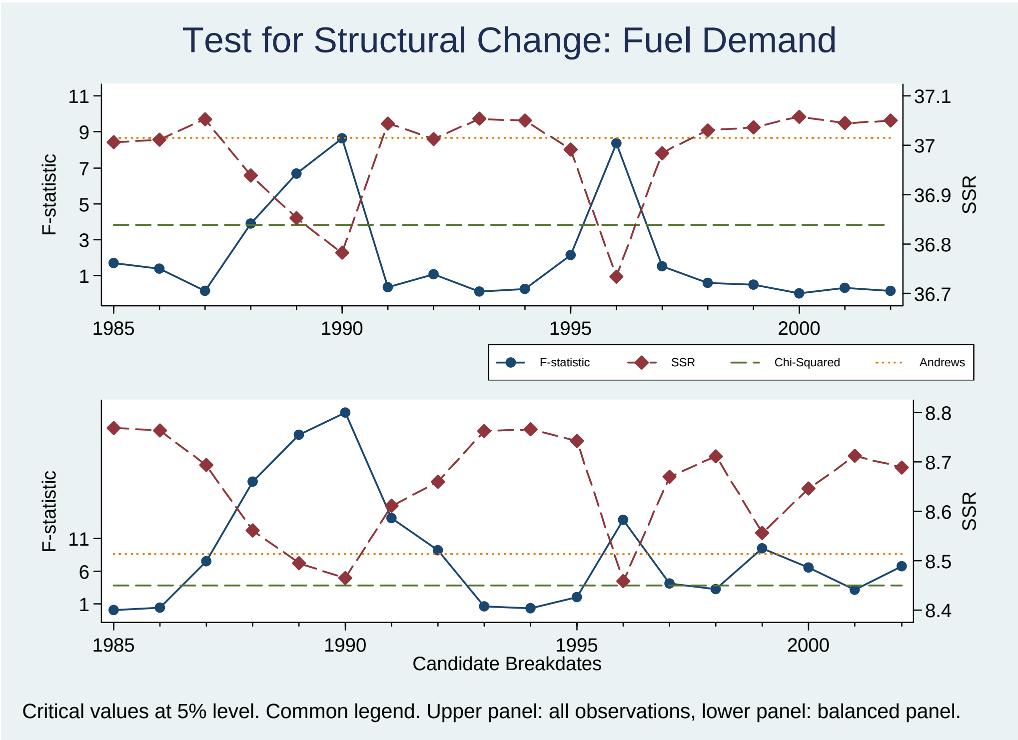

Figure 6: Test for Structural Change: Fuel Demand

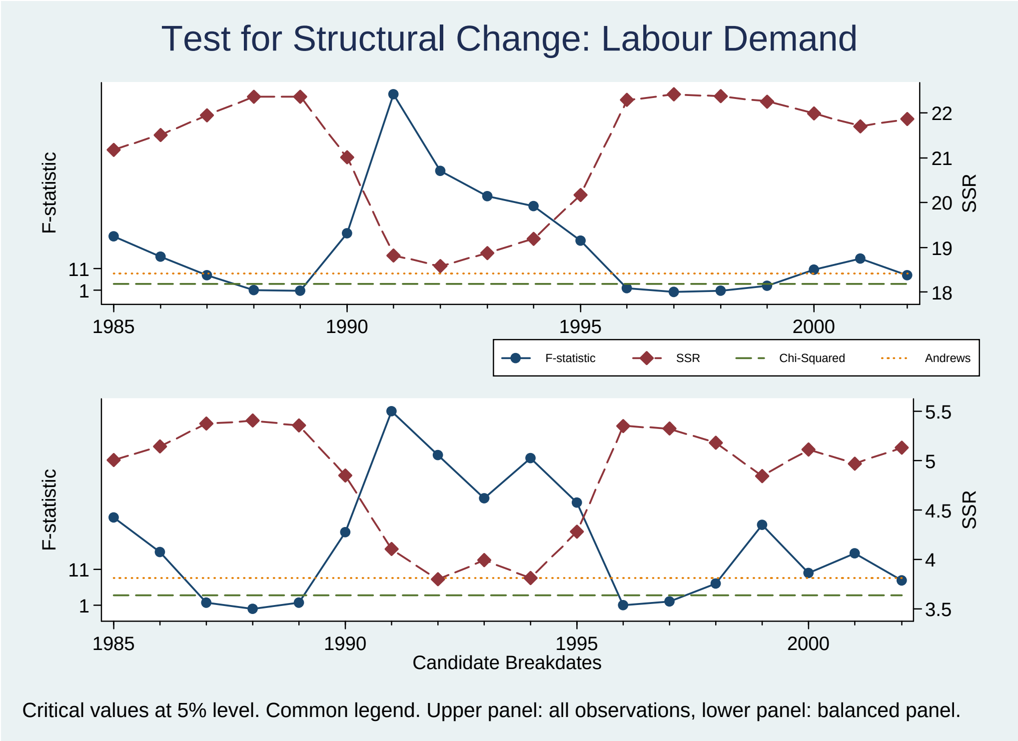

Figure 7: Test for Structural Change: Labour Demand

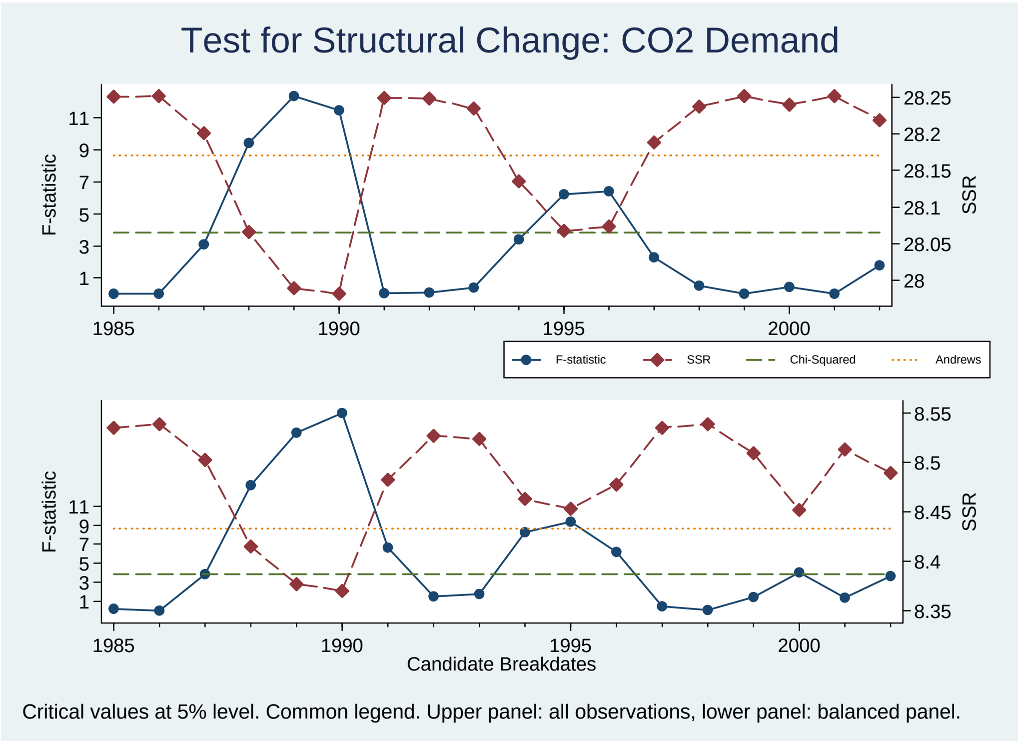

Figure 8: Test for Structural Change: CO2 Demand

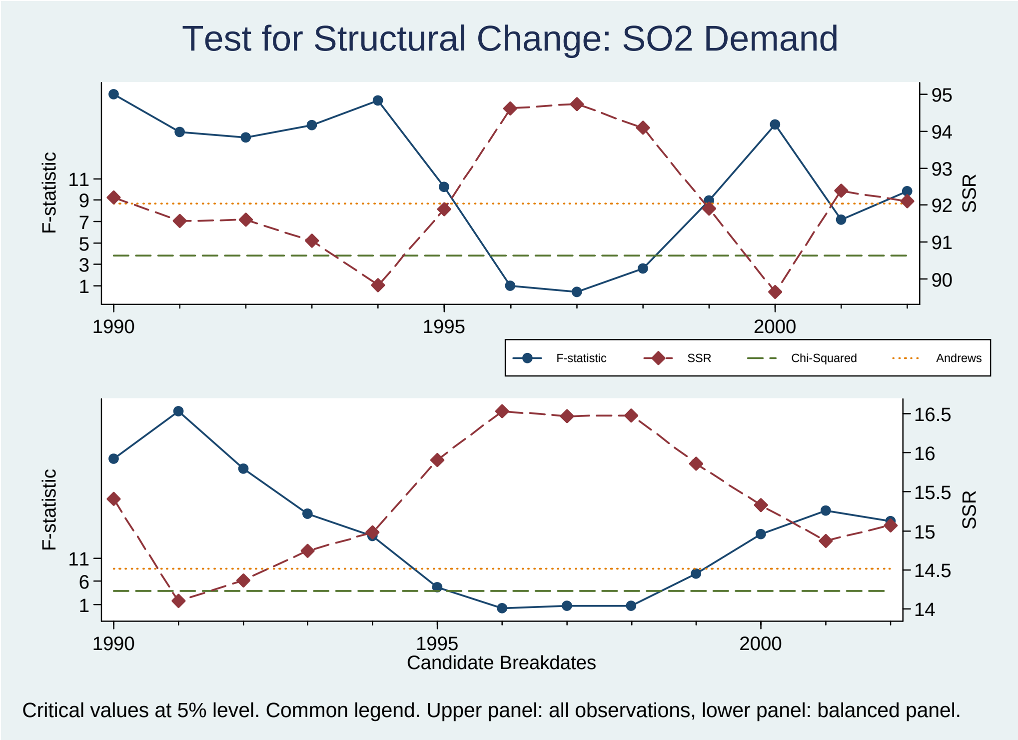

Figure 9: Test for Structural Change: SO2 Demand

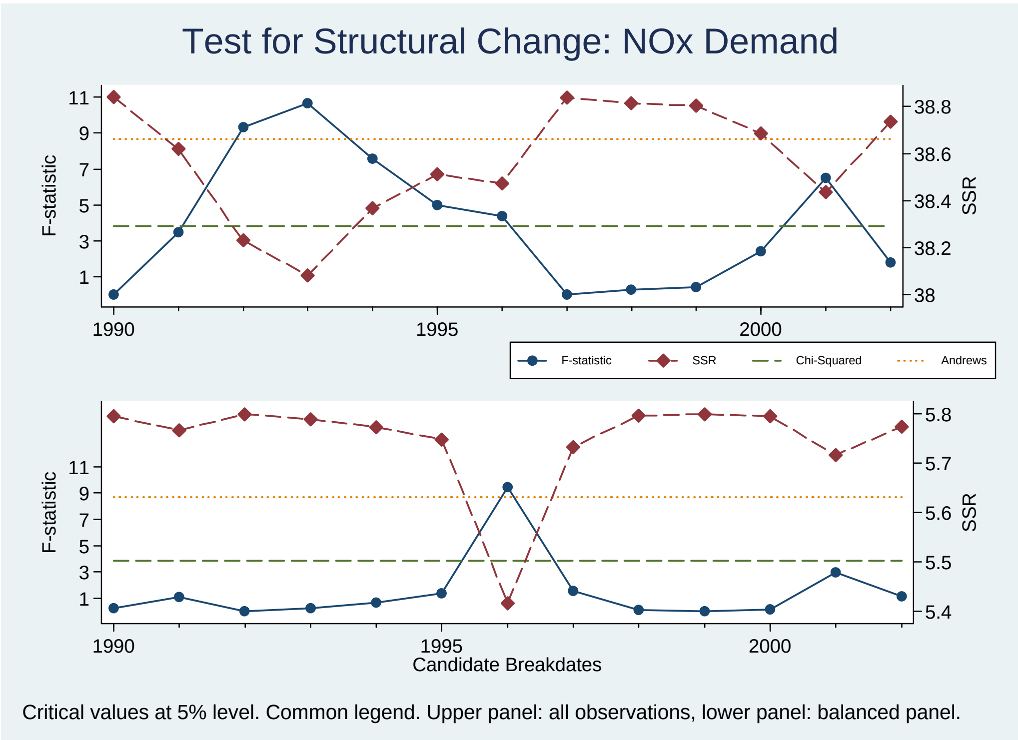

Figure 10: Test for Structural Change: NOx Demand

Table 7: Intercept Change (%)

Year	Fuel		Labour		CO2		SO2		NOx	
	Full	Restricted	Full	Restricted	Full	Restricted	Full	Restricted	Full	Restricted
1985	-2.702	-5.168	31.179	8.774	-1.670	-8.241				
	[0.17]	[0.03]**	[0]***	[0.37]	[0.26]	[0]***				
1986	-3.709	-2.927	26.099	5.614	-2.897	-6.234				
	[0.14]	[0.07]*	[0]***	[0.45]	[0.09]*	[0]***				
1987	-0.437	1.549	18.198	-1.855	0.296	-2.134				
	[0.87]	[0.36]	[0.01]**	[0.8]	[0.87]	[0.16]				
1988	4.492	4.915	2.597	-5.236	4.656	1.303				
	[0.12]	[0.01]***	[0.6]	[0.32]	[0.04]**	[0.37]				
1989	6.604	8.072	-6.597	-7.383	6.211	3.965				
	[0.02]**	[0]***	[0.2]	[0.12]	[0.01]***	[0.08]*				
1990	8.105	11.210	-25.201	-20.619	7.185	6.516	26.537	38.991	-3.117	4.935
	[0.02]**	[0]***	[0]***	[0]***	[0.01]***	[0.06]*	[0.16]	[0]***	[0.66]	[0.52]
1991	2.194	8.687	-39.287	-25.801	-0.187	5.081	21.013	52.977	-12.108	9.189
	[0.59]	[0.01]**	[0]***	[0]***	[0.97]	[0.15]	[0.32]	[0]***	[0.12]	[0.17]
1992	3.292	8.026	-30.388	-23.058	0.351	5.722	17.665	49.481	-19.739	8.002
	[0.43]	[0]***	[0]***	[0]***	[0.91]	[0]***	[0.39]	[0]***	[0.02]**	[0.04]**
1993	1.802	4.726	-33.435	-17.511	-0.969	3.539	22.100	45.528	-23.031	8.687
	[0.54]	[0.01]***	[0]***	[0]***	[0.73]	[0.05]*	[0.23]	[0]***	[0]***	[0.07]*
1994	0.908	1.465	-29.295	-23.906	-2.125	0.602	48.276	43.057	-18.356	6.356
	[0.79]	[0.43]	[0]***	[0]***	[0.44]	[0.7]	[0.04]**	[0]***	[0.02]**	[0.35]
1995	-2.326	0.252	-25.236	-22.461	-4.030	0.629	32.030	25.072	-15.281	2.660
	[0.54]	[0.89]	[0]***	[0]***	[0.26]	[0.69]	[0.15]	[0.07]*	[0.03]**	[0.71]
1996	-5.595	-4.880	-7.226	-5.483	-5.029	2.298	0.055	-1.509	-14.350	-4.787
	[0.1]*	[0.03]**	[0.27]	[0.4]	[0.09]*	[0.19]	[0.94]	[0.94]	[0.01]**	[0.49]
1997	-1.929	-1.495	3.459	16.437	-1.634	5.576	-9.017	-8.833	-4.156	-2.127
	[0.58]	[0.56]	[0.61]	[0.12]	[0.56]	[0.03]**	[0.63]	[0.48]	[0.6]	[0.79]
1998	-1.405	-1.133	9.710	28.389	-0.071	5.498	-11.491	-8.972	1.569	-0.669
	[0.65]	[0.67]	[0.16]	[0]***	[0.99]	[0.03]**	[0.4]	[0.23]	[0.81]	[0.93]
1999	-1.033	-5.927	13.181	34.016	2.493	-0.299	-14.810	-18.438	6.795	-5.326
	[0.73]	[0.05]*	[0.07]*	[0]***	[0.28]	[0.94]	[0.13]	[0]***	[0.28]	[0.34]
2000	0.428	-5.987	11.218	9.197	0.291	-5.309	-22.549	-23.037	10.277	-9.604
	[0.85]	[0.06]*	[0.13]	[0.18]	[0.88]	[0.15]	[0.01]***	[0]***	[0.04]**	[0.07]*
2001	0.980	-4.538	18.722	14.439	0.586	-3.556	-13.070	-25.784	12.995	-5.054
	[0.68]	[0.2]	[0.01]**	[0.08]*	[0.77]	[0.36]	[0.16]	[0]***	[0]***	[0.33]
2002	0.040	-4.788	17.755	13.680	-1.553	-3.396	-18.293	-23.963	8.011	-3.729
	[0.98]	[0.05]*	[0.05]*	[0.16]	[0.42]	[0.28]	[0.08]*	[0]***	[0.09]*	[0.43]

p-values in brackets: *** p<0.01, ** p<0.05, * p<0.1
includes plant-epoch fixed effects

Data calculations

Our sample has many missing values. Where possible we filled missing values as follows:

- Supply is derived from CO2 emissions using generic efficiency measures where necessary (Table 8). The formula is:
  $$GWh(Supply) = kt(CO2) * EF * Eff$$
  where:
  EF = Emissions Factor (Table 10)
  Eff = Thermal Efficiency (actual or Table 8)
  Kt = Thousand tonnes

- Fuel input is derived from CO2. Note that we do not derive fuel input from supply directly. The formula is:
  $$kt(Fuel) = kt(CO2) * EF * CF * CV$$
  where:
  EF = Emissions Factor (Table 10)
  CF = Conversion factor (fuel dependent)
  CV = Heat content (Table 12)
  Kt = Thousand tonnes.

  For gas the equation looks as follows
  $$kt(Gas) = kt(CO2) * \frac{5.26GWh}{kt(CO2)} * \frac{3.6E^{+06}MJ}{GWh} * \frac{1.88E^{-08}\ kt(Gas)}{MJ}$$

CO2 is derived from supply.

Also, for comparability all fuel input amounts are converted in Mtce (million tonnes of coal equivalent) given the fuel's calorific value and the energy content of tce as given in Table 11.

Table 8: Thermal Efficiencies by Fuel

Fuel	Thermal efficiency (%)	Source/Comment
Coal	0.36	DUKES 2005, average 1999-2003
Gas (conventional)	0.36	Assumed to be the same as for coal
CCGT	0.467	DUKES 2005, average 1999-2003
Oil	0.324	Electricity Handbook 1987-1989, average for plants in sample
CHP	0.7	DUKES 2009, Table 6D

Table 9: Plant Load Factors

Year	Conventional Thermal	CCGT
2004	n/a	n/a
2003	50	59.8
2002	42.3	68.4
2001	42.1	66.6
2000	39.4	75
1999	35.3	84

source: DUKES, various years

Table 10: Emissions Factors

Fuel	kg(CO2)/kWh (energy input)	kWh/kg(CO2) or GWh/kt(CO2)
Natural Gas	0.19	5.26
Gas/Diesel Oil	0.25	4
Petrol	0.24	4.17
Heavy Fuel Oil	0.26	3.85
Coal	0.3	3.33
Coking Coal	0.3	3.33
Coke	0.37	2.7

source: DEFRA (2003)

Table 11: Conversion Factors

Energy	1 kWh	3.6 MJ
tce	1 tce	29308 MJ
	1 tce	8.141 MWh

source: MIT[16]

[16] http://web.mit.edu/mit_energy/programs/discussions/disc_2006_Energy101.html.

Table 12: Calorific Values

Fuel	kWh/tonnes	Source/Comment
Coal (weighted average)	7583	DEFRA (2003)
Fuel Oil	11999	DEFRA (2003)
Natural gas	14779	DEFRA (2003) and assuming that 1kg Gas = 53.2 MJ (MIT energy conversion sheet)