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The Impacts of the Climate Change Levy on Business: Evidence from Microdata*

Ralf Martin† Laure B. de Preux‡ Ulrich J. Wagner§

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Abstract

We estimate the impacts of an energy tax – the Climate Change Levy (CCL) – on the manufacturing sector using panel data from the UK production census. Our identification strategy builds on the comparison of trends in outcomes between plants subject to the CCL and plants that were granted an 80% discount on the levy after joining a so-called Climate Change Agreement (CCA). Since the CCAs stipulate specific targets for energy usage or carbon emissions, this comparison yields a lower bound on the impact of the discount. To address a likely selection endogeneity in CCA participation, we adopt an IV approach that exploits exogenous variation in pollution discharges that determined eligibility for CCA participation. We find robust evidence that CCA participation had a strong positive impact on growth in both energy intensity and energy expenditures. An analysis of fuel choices at the plant level reveals that this effect is mainly driven by stronger growth in electricity use and translates into a positive impact on CO2 emissions. We do not find any statistically significant impacts of the tax on employment, gross output or total factor productivity. We conclude that, had the CCL been implemented at full rate for all businesses, further cuts in energy use of substantial magnitude could have been achieved without jeopardizing economic performance.

JEL Classification: Q41, Q48, Q54, D21

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1 Introduction

With climate change climbing ever higher on the political agendas there is now a widespread interest in the effects of different policy instruments designed to reduce greenhouse gas (GHG) emissions from the business sector. Depending on the perspective of the stakeholder, the emphasis is on the environmental effectiveness of such policies, on their costs and benefits, or on their effects on international competitiveness of domestic industry, among others. However, empirical evidence on the impact of climate change policy is scarce, be it for the small number of concrete policies measures that have been implemented thus far or for a lack of suitable data to analyze them.

The single most important climate change policy that the UK government has unilaterally imposed on the business sector thus far is the so-called Climate Change Levy (CCL). The CCL is an energy tax that added approximately 15% to the energy bill of a typical UK business when it was introduced in 2001 (NAO, 2007). The government has sought to reduce the tax burden on energy intensive firms by offering an 80% discount on the tax rate to businesses that join a so-called Climate Change Agreement (CCA) and adopt a specific target for energy consumption or carbon emissions. This policy package was expected to contribute more than half of all carbon savings from the business sector under the UK Climate Change Programme.

Given its scope and institutional context, the CCL package provides a unique opportunity to study the impacts of large-scale regulations of carbon dioxide emissions from the business sector in a post-industrial economy. However, previous assessments of the CCL have struggled with two main problems. First, it has proven difficult to establish generally accepted baselines against which to measure progress of firms in CCAs towards their targets. Second, the use of aggregate energy data in quantitative analyses renders identification of the impacts of the CCL a formidable task, given the dynamically changing economic environment and the concurrent introduction of multiple policies under the UK Climate Change Programme.

This study is the first to bring microdata to bear on these problems. We use longitudinal data on manufacturing plants to estimate the impact of the CCAs on energy efficiency, interfuel substitution, and economic performance. Our strategy to identify the tax effect builds on the comparison of trends in energy use and other outcomes between CCA plants and others. This raises two issues. First, eligibility is not randomly assigned and eligible plants can decide voluntarily if they want to participate in a CCA. We thus expect a fair amount of self selection into CCAs to be present, which would lead to bias in simple least-squares estimates. To address this problem, we adopt an instrumental variable framework that exploits exogenous variation in the initial CCA eligibility rules. Specifically, since eligibility criteria were based on emissions of pollutants regulated under the Pollution Prevention and Control (PPC) Act we can use low-pollution yet energy intensive plants as a control group. The second issue is that a CCA not only entitles a facility to a tax discount, but it also stipulates a target for reductions in energy consumption or carbon emissions. To the extent that this target places a binding constraint on the plant's production choices, we recover a lower bound on the full price effect of the levy discount.

We find robust evidence that CCA participation had a strong positive impact on growth in both energy intensity and energy expenditures. An analysis of fuel choices at the plant level reveals that this effect is mainly driven by stronger growth in electricity use and translates into a positive impact on CO2 emissions. We do not find any statistically significant impacts of the tax on employment, gross output or total factor productivity, which suggests that worries about adverse effects of the CCL on economic performance are unsubstantiated. We conclude that, had the CCL been implemented at full rate for all businesses, further cuts in energy use and carbon emissions of substantial magnitude could have been achieved without jeopardizing economic performance.

The remainder of the paper is structured as follows. Section 2 describes the CCL package in detail. Section 3 reviews previous research on the tax and summarizes the main findings and the assumptions underlying them. Section 4 describes the data sources and summarizes the data set used for the analysis. Section 5 describes our research design and our econometric framework. Section 6 reports our main results and presents several robustness checks. Section 7 concludes.

2 UK Climate Policy: Climate Change Levy and Climate Change Agreements

2.1 Background

The UK signed the Kyoto Protocol[1] in 1998 with a commitment to reduce its GHG emissions by 12.5% from 1990 levels until 2012, as stipulated under the terms of the EU Burden Sharing Agreement. In addition, the Blair administration promised to put the country on a path leading to more ambitious CO2 reductions in the short and medium run, such as a 19% cut by 2010 (in the 2000 Climate Change Programme) and a 60% reduction by 2050 (in the Energy White Paper 2003). With the passing into law of the Climate Change Bill in November 2008, the commitment to reduce GHG emissions in the UK by at least 80% until 2050 has become legally binding.[2]

In the subsequent analysis, we focus on the single-most important policy package that the British government has implemented unilaterally in order to achieve its ambitious abatement targets.[3] The Climate Change Levy package combines an energy tax (the CCL) with a negotiated agreement scheme (the CCAs) by which firms in eligible sectors adopt binding energy (efficiency) targets in exchange for a generous discount on the tax rate. The CCL was first announced in March 1999 and came into effect in April 2001. The levy was designed to promote energy efficiency rather than absolute reductions in carbon emissions (NAO, 2007). The government estimates that combined carbon savings from the CCL and CCA will amount to 6.6 MtC in 2010, making it the top contributor towards a projected total reduction of 20.8 MtC to be achieved by the Climate Change Programme 2006 (HM Government,

[1] The Kyoto Protocol, adopted in 1997, is a protocol for action following the global action plan of the UN Framework Convention on Climate Change. Developed countries have agreed "[...] individually or jointly, [to] ensure that their aggregate anthropogenic carbon dioxide equivalent emissions [...] do not exceed their assigned amounts, [...] with a view to reducing their overall emissions of such gases by at least 5 per cent below 1990 levels in the commitment period 2008 to 2012" (Article 3, point 1).

[2] It is permissible, however, that part of this reduction may be achieved through action abroad.

[3] Only the second phase of the EU ETS is expected to bring larger carbon savings.

2006). Next we shall explain the fundamental aspects of both policies in more detail.

2.2 The Climate Change Levy

The CCL is a per unit tax payable at the time of supply to industrial and commercial users of energy. Taxed fuels include coal, gas, electricity, and non-transport Liquefied Petroleum Gas (LPG). For each fuel type subject to the CCL, table 1 displays the tax rates per kilowatt hour (kWh, column 1), the average energy price paid by manufacturing plants in 2001 (column 2) and the implicit carbon tax (column 3). Energy tax rates vary substantially across fuel types, ranging from 6.1% on coal to 16.5% on natural gas.[4]

While the tax establishes a meaningful price incentive for energy conservation overall, we can see that individual tax rates give rise to a perverse effect in that the carbon contained in gas and electricity is taxed at almost twice the rate as carbon contained in coal. David Pearce (2006) attributed this to political pressures arising from historical ties between the Labor Party and the coal industry, which had suffered from the dash for gas over the 1990s.[5] Some fuel types are tax-exempt based on their low carbon content, notably electricity generated from renewable sources and and from combined heat and power. Hence, rather than a pure carbon tax the CCL can be characterized as a de-facto tax on energy with non-uniform rates, shaped by a mixed bag of fiscal goals.

Revenue from the CCL is, to a large extent, recycled back to industry in the form of a 0.3% reduction of the employer contribution to National Insurance Contributions (NIC). A small part of the revenues are diverted to the *Carbon Trust*, an institution set up by the government to foster research and development into energy efficiency schemes and renewable energy resources.

2.3 The Climate Change Levy Agreements

For fear of possible adverse effects of the CCL on competitiveness and economic performance of energy intensive industries, the government set up a scheme of negotiated agreements, the CCAs. By participating in a CCA, facilities in certain energy intensive sectors can reduce their tax liability by 80% provided that they adopt a binding target on their energy use or carbon emissions. This process involves two stages. First, the sector association negotiates a so-called *umbrella agreement* with the government (represented by DEFRA, the Department of Environment, Food and Rural Affairs) to determine a sector-wide target for energy use or carbon emissions in 2010, as well as interim targets for each two-year *milestone period*. Targets are defined either in absolute terms or relative to (often physical units of) output. At the second stage, firms in eligible sectors apply for a *reduced-rate certificate* that entitles them to the discount on the levy paid at a qualifying site. If the application is approved these firms enter a so-called *underlying agreement* with DEFRA which defines the *target*

[4]Tax rates were constant between April 2001 and March 2007, and were adjusted for inflation only in April 2007.

[5]Similarly, mineral oil was exempt from the tax because it was already covered by the rather unpopular fuel duty escalator that raised the tax on diesel and gasoline on an annual basis. Residential energy use was not taxed for fear of a possible regressive effect (Pearce, 2006).

unit, i.e. the facility or group of facilities benefiting from the tax discount, and stipulates a specific reduction to be achieved by the target unit.[6]

Towards the end of each milestone period (i.e. 2002, 2004, 2006, 2008) the sector associations report to DEFRA whether the sector-wide target has been met. Only if a sector-wide target has been missed does DEFRA verify compliance at the target unit level. A facility that is found in non-compliance is not *re-certified* for the reduced rate in the following milestone period. If the facility misses the 2010 target it faces the threat to repay all rebates on the levy it has accumulated in previous periods.

Eligibility to enter a CCA is confined to facilities in certain energy intensive sectors. For lack of a clear-cut definition of these sectors, the government initially determined eligibility based on existing pollution regulation, namely the Pollution Prevention and Control (PPC) Act 1999.[7] CCAs were open to businesses carrying out activities regulated under part A of the PPC Act, which included emission limits and other permit conditions in relation to releases to air, water and land, waste minimization, energy efficiency and site restoration. In 2006, the eligibility criteria were extended to take into account the energy intensity of businesses following the definition underlying the EU Energy Products Directive NAO (2007).[8]

CCA participants not in compliance could meet their target by buying emission allowances on the UK Emissions Trading Scheme (UK ETS), a market for carbon permits that was launched in 2002 and ended in December 2006. Conversely, excess carbon or energy reductions could be sold in the UK ETS or *ring-fenced* (banked) for use towards future targets. All transfers of permits from the relative sector to the absolute sector are subject to approval by the authority according to a *Gateway* mechanism which only allows such transfers provided that there is no net aggregate flow of permits from sectors with relative targets to sectors with absolute targets.[9]

DEFRA originally negotiated 44 umbrella agreements with different industrial sectors, including the ten major energy intensive sectors (aluminium, cement, ceramics, chemicals, food and drink, foundries, glass, non-ferrous metals, paper, and steel) and over thirty smaller sectors. Sector definitions rarely coincide with common economic classification systems. While most sector associations have chosen relative targets for energy, absolute targets were negotiated for the aerospace, steel, supermarkets and wall coverings sectors. Carbon targets were negotiated for the aluminium and packaging (including metal packaging) sectors. Table 2 summarizes the coverage of agreements and sectors throughout the first three target periods.

[6]In practice, underlying agreements are made either between sector associations and companies and are subsequently approved by the Secretary of State, or directly between the Secretary of State and individual companies (NAO, 2007).

[7]This act transposed EU Directive 96/61 on Integrated Pollution Prevention and Control also known as the "IPPC Directive" or as Directive 2008/1/EC)

[8]This recent change in the definition does not directly affect the subsequent analysis because it is based on data only for the years until 2004.

[9]Smith and Swierzbinski (2007) note that the Gateway has been open since the scheme began due to surplus allowances from so-called direct participants who opted into the UK ETS.

3 Has the CCL package improved energy efficiency?

While the primary objective of both the CCL and the CCA is to enhance the efficiency of energy use in the business, the two instruments take different roads to achieve it. The levy provides a price signal at roughly 15% of energy prices faced by the typical business in 2001 (NAO, 2007). If energy demand is price sensitive, the increased relative price of energy should lead to improvements in energy efficiency and - in the absence of a strong rebound effect or exogenous increases in economic activity - to a reduction in energy use. Since even the effect of an absolute reduction in energy use could in principle be offset by a shift towards more carbon-intensive fuels, the levy's impact on carbon emissions is ambiguous.

In contrast, the CCA combines a much more diluted price signal with quantity regulation, mostly in the form of efficiency targets. Hence the impact of the CCA on a plant's energy use depends crucially on whether the target places a binding constraint on the dynamic trajectory during the plant's remaining economic lifetime. Clearly, if this is not the case, the plant faces weaker incentives for energy conservation than it would under the full tax rate. It is thus not surprising that much of the previous research on the CCAs has centered around the stringency of targets. It is worth noting that, since most targets are specified in terms of energy units rather than carbon emissions, there is no guarantee that even a stringent target leads to reductions in GHG emissions.

3.1 How stringent are the targets negotiated in the CCAs?

In a theoretical analysis, Smith and Swierzbinski (2007) show that a government with perfect information could have used its bargaining power vis-à-vis firms to extract abatement concessions equal to or in excess of the abatement conducted under the full tax rate. However, it does not seem very plausible that the government had perfect information about firm-specific abatement cost, especially if firms were worrying that sharing this information with the government could compromise their bargaining position in the impending negotiations. Moreover, the government may not have been willing to drive a hard bargain because of concerns about adverse effects on competitiveness and about exacerbating the distortions in marginal abatement cost (de Muizon and Glachant, 2003; Smith and Swierzbinski, 2007). The remainder of this section attempts to assess the stringency of the CCA targets based on a close inspection of how the targets were established, how their fulfillment has been measured and monitored, and how compliance has been enforced.

DEFRA hired the consultancy AEA Technology plc. (AEAT) for independent advice on and practical assistance with the negotiation of the targets.[10] AEAT had previously conducted assessments of the potential for energy efficiency improvements in a number of energy intensive sectors which had been commissioned by DEFRA's Global Atmospheric Division (GAD). The 1999 GAD assessment comprised a "business as usual" scenario and an "all cost effective" scenario. In the latter, firms implement all efficiency enhancing measures – including operational changes, low-cost retro-fit measures, major plant investments, and CHP – which were cost effective without placing restrictions on the availability

[10] To be precise, the CCAs were handled by a consultancy owned by AEA Technology called ETSU (now Future Energy Solutions).

of management time and capital. Sector targets were set in such a way that they would, on average, close 60% of the gap between the "business as usual" and "all cost effective" scenarios (AEAT, 2001).

AEAT estimated that annual carbon savings from the 10 main CCA sectors at 2.5MtC by 2010, holding output fixed at 2000 levels in sectors with relative targets (HMCE, 2000).[11] Measured against this baseline, the combined annual carbon savings in all CCA sectors have been substantially larger than both the milestone and 2010 target throughout the first three milestone periods. For the first milestone period, CCA sectors reported savings of 4.5MtC (3.9MtC and 4.5MtC, respectively, in subsequent milestone periods) against baseline emissions, most of which (2.6MtC) was due to a dramatic decline in steel production. Even without the 4 sectors with absolute targets there was significant overcompliance with carbon savings estimated at 3MtC (3.9MtC and 4.3MtC, respectively, in subsequent milestone periods). These numbers are obtained by multiplying the observed efficiency improvements with base year output (NAO, 2007).

The extent of overcompliance of CCA sectors with their 2010 targets raised suspicions that the targets were indeed closer to business as usual than the AEAT analysis would grant. In fact, AEAT's estimated mean improvement in energy efficiency in GAD sectors of 4.8% between 2000 and 2010 is much lower than alternative estimates. For the same period, the EU Energy Outlook estimated a 9.5% improvement for all UK industry and DTI Energy Paper 68 predicted an improvement of 11.5%.[12] Since the average 11% reduction target to be achieved by CCA sectors falls well into this range, the Association for the Conservation of Energy objects that the government "double counts" carbon savings from the CCA scheme (ACE, 2005).

A number of further observations point to the possibility that the negotiated targets were indeed rather lax. The proportion of target units that were re-certified was consistently high, rising from 88% in the first period to 98% and 99% in the second and third target periods, respectively (AEAT, 2004, 2005, 2007). Most CCA participants reached their targets, and those who did not could purchase allowances on the UK carbon trading market to close the gap at low cost. Due to significant oversupply of carbon credits, carbon prices have remained low, fluctuating between £7 and £15 per ton of carbon (£2 and £4 per ton of CO2 equivalent) for most of the period. which is lower than most of the implicit carbon tax rates displayed in table 1.[13] In fact, the lower bound on compliance cost is zero, as a considerable amount of target units that missed their target were re-certified for subsequent milestone periods because the sector as a whole met its target.[14]

Finally, there was a large degree of flexibility built into the target negotiations both prior and subsequent to the compliance review. Ex post flexibility allowed target units to call upon to several *risk*

[11]Remarkably, AEAT further estimated that only 10% of this reduction would have been attained had CCA firms been taxed at the full rate (AEAT, 2001) which suggests that their "business as usual" forecast exhibits either very slow "autonomous" energy efficiency improvements or a low price elasticity of energy demand, or both.

[12]This accounts for the effect of the CCL alone without CCAs.

[13]Smith and Swierzbinski (2007) document that the market price of CO2 allowances was consistently lower than supply bids in the initial auction. These authors furtherconjecture that sellers of allowances could meet their targets with relative ease. Allowance trade experienced increased activity as firms participating in CCAs bought allowances to meet their interim targets in March 2003 and March 2005, respectively, but the demand for permits was not large enough to put upward pressure on the price.

[14]For example, after the 2004 milestone, approximately 250 non-compliant target units were re-certified because of this (NAO, 2007).

management tools that made it easier to meet their targets. Adjustments to targets could be made to reflect a more energy intensive product mix, declining output (if minimum energy use was spread over fewer units), or *relevant constraints* arising from other types of regulation. In some sectors, performance was measured against a *tolerance band* in lieu of a fixed target. These risk management tools had to be approved by the government, and some of them were discontinued in later periods (NAO, 2007).

Ex ante flexibility was ensured by permitting each sector to choose its own baseline year. More than two thirds of all sectors chose baseline years of 1999 or earlier, in some cases going back as far as 1990. This means that carbon savings that had occurred before the policy package was implemented or even announced could be counted towards the target achievement (NAO, 2007). Furthermore, in some instances growing companies that belonged to a sector with an absolute target successfully bargained for a relative target (and vice versa) as this made it easier to comply.

In sum, there is ample evidence that the negotiated targets are unlikely to have placed binding constraints on energy use by CCA companies.

3.2 Previous assessments of the effectiveness of the CCL package

In its 2000 Regulatory Impact Assessment, the government projected the CCL element alone to achieve carbon savings of at least 2 MtC in 2010 against business as usual projections (HMCE, 2000). This estimate came from a model of business energy use based on energy price elasticities maintained by the Department of Trade and Industry (DTI).[15]

An official study commissioned by HM Customs & Excise and conducted by Cambridge Econometrics was published at the end of the second commitment period (Cambridge Econometrics, 2005). The study is based on a macroeconometric forecasting model (MDM-E3) of the UK economy that explicitly accounts for energy-environment interactions. The study's key finding is a reduction in energy demand by the service and public sectors (which excludes manufacturing) following the announcement of the CCL package in March 1999. The authors identify this "announcement effect" in the form of a structural break in quarterly energy demand and further argue that the effect is permanent rather than transitory.[16]

Moreover, the authors use MDM-E3 model to forecast business energy use with and without the introduction of different versions of the CCL package. They conclude "that the energy (and therefore carbon) saving and energy-efficiency targets would have been met without the CCAs" (Cambridge Econometrics, 2005, p. 7).[17]

Using the same model, Ekins and Etheridge (2006) compare simulated carbon savings from the CCL package as is and a from a levy only that is applied at full rate across sectors. They obtain a difference

[15] To put this into perspective, carbon emissions from the business sector were estimated at 60.3MtC in 2000 (NAO, 2007).

[16] The estimation is based on error correction models using quarterly data on sectoral energy demand. See Agnolucci et al. (2004) for a detailed description of this part of the study.

[17] With the exception of the "other industry" sector, which comprises all manufacturing other than basic metals, mineral products and chemicals, the authers find that the targets would have been met at the reduced rate or even without any CCL at all.

of 0.9 MtC between both scenarios, which is smaller than the excess carbon savings of 1.7 MtC that AEAT (2004) computed for the relative target sectors in the first milestone period. Since their model does not account for this difference they conclude that "the CCL package as implemented [...] achieved a greater carbon reduction than a no-rebate CCL would have done by itself." (Ekins and Etheridge, 2006, p. 2079). They attribute this phenomenon to what they call an "awareness effect" of the CCA, i.e. the possibility that managers become aware of cost-effective efficiency enhancement projects only as they start to benchmark their energy use.[18] Another version of the MDM-E3 model is used by Barker et al. (2007) to simulate the impact of the CCAs on macroeconomic outcome variables such as output, employment and the rebound effect in industrial energy demand. In their exercise, however, a large effect of the CCAs on sectoral energy demand - averaging a 9.1% reduction in sectoral energy use by 2010 - is built into the model rather than estimated.

3.3 Synthesis

In summary, the existing reviews and evaluations of the CCL package illustrate two fundamental difficulties in policy evaluation, namely (i) to determine a valid baseline against which to measure the impact of a policy and (ii) to attribute any measured impact to this policy in a causal fashion.

Previous studies have adopted simulated trajectories of energy use as a baseline against which to measure the impact of the CCL package, and their results have been shown to critically depend on those counterfactual baselines. By definition, counterfactual scenarios are not observable, hence the evaluation results are subject to a large degree of uncertainty. In the case of simulations with a macroeconometric model, this uncertainty derives not only from compounded error in the estimation of the underlying parameters but also from the possibility of changes in the economic environment, structural changes in the parameters - or, for that matter, from changes to the policy itself.

Furthermore, previous quantitative evaluations of the levy package have relied on time series data aggregated at the sector level. While aggregate data can provide important clues for evaluating the effects of a policy, they rarely deliver conclusive evidence in terms of discerning the effects of the policy from other concurrent events in a dynamically changing economic and political environment. When the levy package was introduced, energy markets in the UK had been undergoing important changes that entailed significant and prolonged adjustments to prices, notably declining electricity prices and increasing prices of gas and coal. The levy interacted with a number of pre-existing other taxes in the business sector, such as National Insurance Contributions and the Fuel Duty Escalator. Not least, with the Enhanced Capital Allowance and Carbon Trust energy audits, other energy efficiency enhancing measures were introduced simultaneously.

This study is the first to use longitudinal business microdata for an evaluation of the Climate Change Levy package. We use panel data at the establishment level to estimate the impacts of the CCAs on energy efficiency, interfuel substitution, and economic performance. The estimate is based on com-

[18]It bears noting that, as contributors to the Cambridge Econometrics (2005) study, Ekins and Etheridge (2006) had found that the CCA targets would have been achieved even without a tax by 2010 in all but one sector. For there to be a real "awareness effect" of the negotiated agreements, one must hence assume that *any* counterfactual scenario would have resulted in lower carbon savings during the first milestone period.

parisons of establishments before and after the introduction of the policy package, and on comparisons between establishments paying the full levy rate and those entitled to the 80% rebate. Our approach addresses the baseline problem by comparing *changes* in *actual* firm behaviour under two types of policy regimes, thus purging the effect of shocks at the economy, sector or region level. Moreover, we identify the causal effect of the tax rebate by exploiting a quasi-random element in the eligibility rules for participation in the CCAs.

4 Data

4.1 Data sources

In order to evaluate the impact of the CCL we have constructed a novel data set by matching two confidential business data sets and augmenting it with publicly available data on participation in the CCA. At the core of our data set is the Annual Respondents Database (ARD), the main business data set maintained by the Office for National Statistics (ONS). The ARD is an annual production survey that covers about 10,000 plants in the manufacturing sector.[19] Larger plants are sampled every year whereas smaller plants are included on a random basis.[20] The ARD comprises a wide range of economic characteristics of the plant, including turnover, value added, total purchases of goods and materials, employment number and costs, inventories, and net capital expenditure. Core ARD data are available from the 1970s until 2006. Since 1999 the ARD also contains a few questions of direct relevance for this research, such as expenditures on total energy used in the running of the business.

The Quarterly Fuels Inquiry (QFI) is a quarterly survey among a panel of about 1,000 manufacturing plants managed by the ONS on behalf of DTI. The survey collects data on prices and quantities for all relevant fuel types, including medium fuel oil, heavy fuel oil, gas oil, LPG, coal (graded, smalls), hard coke, gas (firm contract, interruptible contract, tariff), and electricity. Our sample covers the period from 1993 to 2004. We can match the majority of the observations in the QFI relatively easily to the ARD because both surveys use the same underlying government business register as their sampling frame. However, because of random sampling in the ARD we do not have ARD data on all QFI plants.[21]

We gathered information on CCA participation from both the DEFRA and HM Revenue & Customs (HMRC) websites. Lists of facilities party to the original sector agreements were downloaded from DEFRA's website.[22] The agreements stipulate the certification periods, the sector targets along with the details on the calculation of the units of energy used and carbon emissions. They also contain a list of all facilities initially covered by the CCA. Seven agreements lack sufficient information on the

[19]Here and in the remainder of the paper a "plant" corresponds to a so-called ARD reporting unit. This is the lowest aggregation level for which production data are available in the ARD. In 80% of all cases a reporting unit is indeed a business unit at a single mailing address. However, some larger plants are allowed to report on several business units combined so as to reduce compliance costs. For more details see Criscuolo et al. (2003).

[20]The cut-off point has varied over the years. In later years it has been at 250 employees. For more details see Criscuolo et al. (2003).

[21]For more details on the QFI and its combination with ARD data see Martin (2006).

[22]http://www.defra.gov.uk/environment/climatechange/uk/business/cca/umbrella.htm

facilities covered by the CCA and thus needed to be excluded from the analysis.[23] The HMRC website provides, sector by sector, the list of facilities that have joined the CCA with the date of publication.[24] The lists are regularly updated and facilities that have resigned from the CCA are removed. We have merged the DEFRA and HMRC lists to obtain a complete list of facilities that pay the reduced rate of the CCL.[25] We match this information to the ARD and QFI by combining information on a plant's postcode and the Company Register Number.

4.2 Descriptive statistics

Table 3 summarizes the main variables from the ARD data set, namely age, number of employees, gross output, variable cost, capital stock, energy expenditure, as well as the percentage of energy expenditures in gross output and in variable costs. The data are summarized for our regression sample running from 1999 until 2004. The data exhibit a substantial amount of dispersion between plants in energy intensity. For example in terms of energy expenditure over gross output (row 7) a plant at the 90th percentile (column 6) has an energy intensity that is more than 12 times higher than that of a plant at the 10th percentile (column 5).

Tables 4 and 5 show the descriptive statistics of the variables in the QFI sample and for the joint sample of QFI and ARD observations. The variables are electricity, liquid fuels, gas, solid fuels such as coal, and total energy use. We report both quantities consumed and expenditures paid for all fuel variables. Moreover, the table lists the share of gas in the consumption of both gas and electricity and the corresponding expenditure shares. We compute total CO2 emissions (in thousands of tonnes) on the basis of the fuel use.

Table 6 shows the descriptive statistics for all samples in the year 2000, broken down by CCA participation status. It also reports the results of a t-test of equality of the group means (assuming unequal variance of the two groups). It is evident that participation in CCAs is not random: CCA plants are, on average, older, larger and more energy intensive, and for most of these plant characteristics equality is rejected at the 1% significance level. Given that CCA participation is obviously correlated with observable plant characteristics, we cannot rule out the possibility that unobservable plant characteristics also influence selection. Our identification strategy must therefore take due account of this possibility to avoid inconsistent estimation due to sample selection and omitted variable bias.

In the subsequent analysis we focus on the first two target periods, i.e. April 2001 until December 2004. While this is dictated by the time coverage in our data set, it also avoids possible complications due to (i) an overlap with the EU ETS which affected about 500 CCA plants from 2005 onwards, (ii) adjustments of CCAs targets for the third milestone period, and (iii) new entry of sectors in 2006 after eligibility had been changed. What is more, since the QFI data only cover manufacturing plants, we limit the analysis to the manufacturing sector.

[23]The craft baking sector and the meat processing sector do not contain a list of facilities. Another five sectors lack facility addresses, namely the NFU poultry meat production sector, the pig farming sector, the egg production sector, the British Poultry Meat Federation farms sector, and the British poultry meat federation processing sector.

[24]The date of publication is the date from which the CCA is applicable.

[25]We thus do not have information on facilities that joined a CCA after 2001 and dropped out after the second target period. Given the high re-certification rate after milestone 2, this should affect our results only in minor ways.

5 Research design

The key idea underlying our research design is to identify the effect of an energy tax – the CCL – by comparing plants that are in a CCA and therefore get an 80% discount on the CCL, with plants that are not. Consequently, our approach follows the literature on programme evaluation and treatment effects where the treatment of interest is CCA participation (Rosenbaum and Rubin, 1983; Angrist et al., 1996). Given the issue at hand, there are three fundamental issues that need to be addressed. First, while CCA plants receive a tax discount they are also subject to an energy consumption or efficiency target which might affect their choices. Second, participation in a CCA is voluntary but not every plant is eligible. This potentially creates a selection endogeneity in the treatment population. Finally, even if we correctly identify the treatment impact on the treated plants we might not necessarily have established the impact that the same treatment would have on plants that are currently not treated. Likewise, the tax might have heterogeneous impacts among the group of treated plants. We shall discuss each of these issues in turn.

5.1 CCA targets

From our review of previous evaluations in 3.1 we concluded that the CCA targets were unlikely to impose binding constraints on firm behavior. If this is true, our estimate recovers the full effect of an 80% reduction in energy taxes, which amounts to an energy price drop on the order of 10% for a typical business.[26] In contrast, our estimate falls short of the true price effect if plants cannot choose optimal levels of energy under the lower tax rate because doing so would violate their CCA target. Our empirical framework is thus geared to providing us with a *conservative* estimate of the impact of the CCL. Figure 1 illustrates this point. The reader should bear in mind, however, that the stringency of CCA targets, though relevant for the interpretation of the estimated effect as a lower bound on the full tax effect, does not affect the consistency of the procedure we use to arrive at this estimate.[27]

5.2 Endogeneity of CCA participation

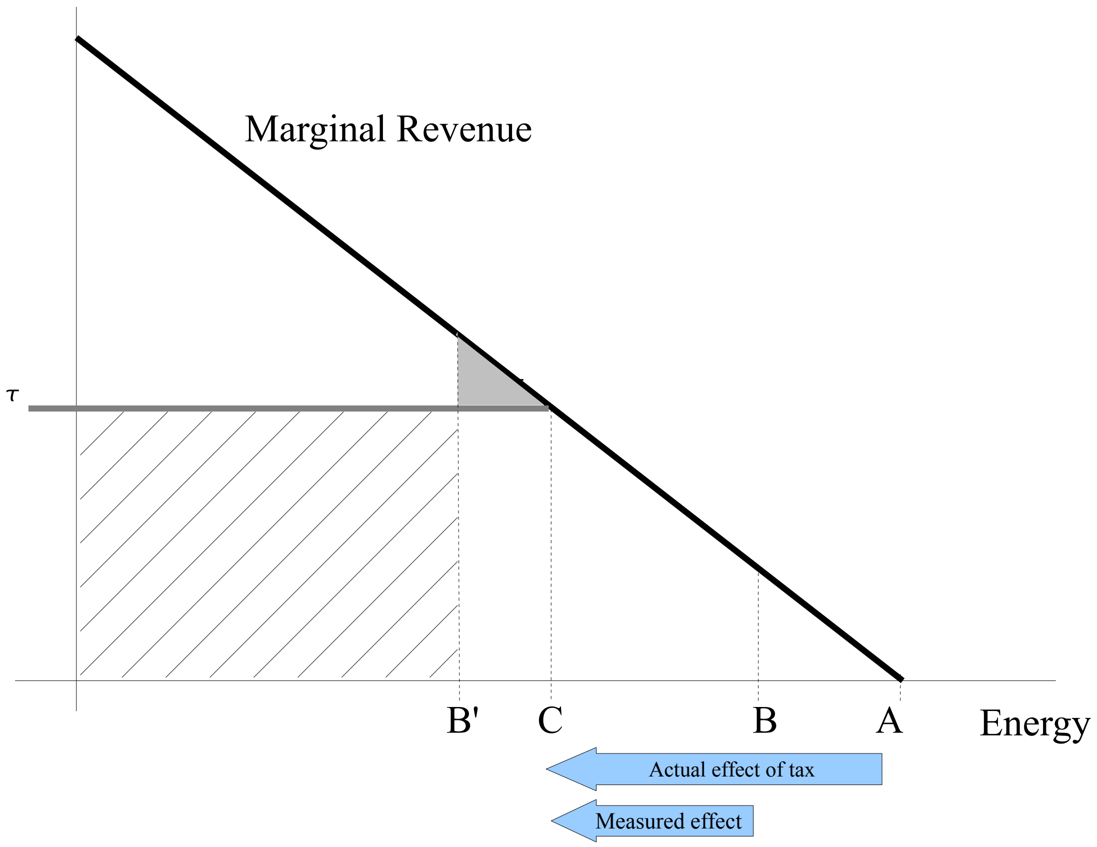
Irrespective of how we interpret the treatment effect we identify, how can we make sure that it picks up the *causal impact* of CCA participation on plant outcomes? The issue that arises in this context is one of non-random selection of plants into agreements.[28] It is easy to find reasons why plants with different levels of the outcome variable prior to treatment might have differing incentives to join a CCA. For example, plants using more energy have more to gain – in absolute terms – from a discount on an energy tax than plants with lower levels of energy consumption. If there are fixed costs for

[26] According to HMRC estimates, the full-rate CCL added about 15% to the energy bill of a typical business (NAO, 2007). The energy price reduction from the CCL discount can thus be calculated as $\frac{0.8 \cdot 0.15}{1.15} = 10.4\%$. The reduction is smaller if the tax is in part borne by energy suppliers.

[27] For example, if the targets were more stringent than the full-rate tax then our method would lead to a negative coefficient on CCA participation. This would still be a lower bound on the tax effect, although not a very meaningful one.

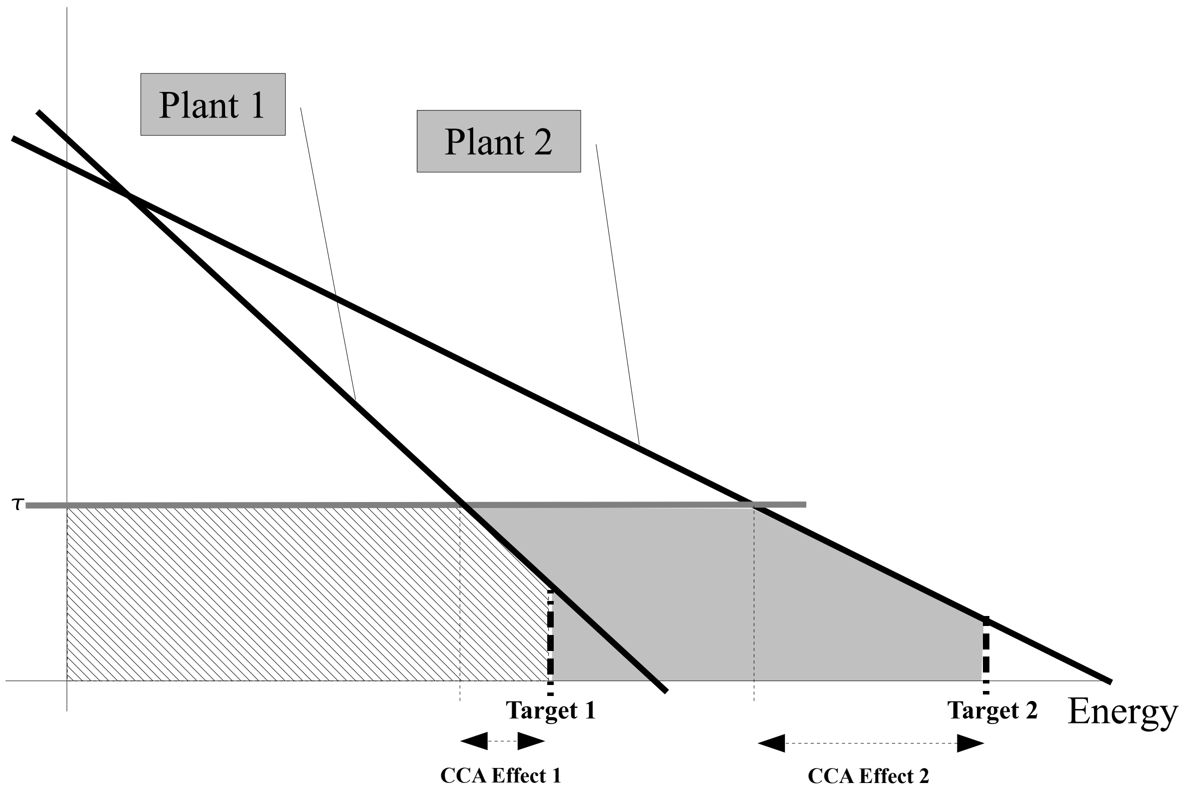
[28] Indeed in section 4.2 we found direct evidence that CCA plants are, on average, older, larger and more energy intensive. Further, we detailed that elibigility rules precluded participation of plants with certain characteristics.

Figure 1: Target vs. Tax Effect



Notes: Suppose without tax or climate change agreement a plant's optimal energy consumption is at A. With a tax τ the optimal consumption reduces to C. If the target set by a Climate Change Agreement (CCA) is at an intermediate point such as B, comparing CCA and non CCA plants provides a meaningful lower bound for the impact of the tax. On the other hand if the target is at B' we would not be able to identify the decrease in energy consumption from A to C due to the tax. For simplicity we normalised the graph so that the reduced CCA tax rate coincides with the horizontal axis.

Figure 2: Selection into CCA



Notes: Consider two plants with different marginal revenue schedules. Even if both plants have a target that implies the same absolute reduction of energy consumption, the plant with the higher revenue curve (plant 2) has more to gain from joining a CCA. Plant 2's gain equals the sum of grey and diagonally striped areas whereas plant 1's gain equals the striped area only.

participating in a CCA the latter might find it more profitable not to join.[29] Figure 2 illustrates this graphically. Thanks to having panel data we can control for selection based on persistent heterogeneity across plants by analyzing within-plant changes in outcome variables.[30] That is, we compare the change in an outcome variable y_{it} before and after the introduction of the CCL package in 2001 between CCA and non CCA firms:

$$\mathbb{E}\left[\Delta y_{it}|CCA=1\right]-\mathbb{E}\left[\Delta y_{it}|CCA=0\right]$$

where $\Delta y_{it} \equiv y_{it} - y_{i2000}$ and $t > 2000$.[31] To simplify the discussion that follows assume that y stands for a plant's energy consumption although we consider a variety of different outcomes variables in our results below.

[29] In personal communication, representatives of CCA sector associations pointed out multiple sources of fixed costs to us. The main cost drivers are payments to consultants or staff for doing the necessary energy accounting and administrative work as well as administrative fees charged by the sector associations.

[30] This is in keeping with the approach taken in recent evaluation studies of other large-scale environmental regulations, see e.g. Greenstone (2002) on the effects of the US Clean Air Act.

[31] In our regressions below we estimate the CCA effect at various years after 2000 as well as the average effect over all post treatment years in the sample (2001-2004).

We can implement this empirically in a simple least-squares estimation of the regression equation

$$\Delta y_{it} = \alpha \Delta CCA_{it} + \nu_{it}. \tag{1}$$

This is valid if the error term $\nu_{i\tau}$ is mean independent of CCA participation, i.e. if a plant's participation decision is not systematically driven by unobserved shocks to energy consumption growth. Clearly, this might not be the case. Suppose, for example, that the government imposes the same reduction target relative to current consumption for all plants. For plants that are planning to expand their energy consumption this may impose a binding constraint and therefore prevent them from joining the CCA, whereas plants that expect a reduction in consumption may be better off by joining if the fixed cost is not too large. In the regressions we control for this in two ways. First, we augment equation (3) by including a vector x_{it} of exogenous plant characteristics such as age controls and dummy variables for region and sector. Second, we include year effects ξ_t and a plant specific fixed effect η_i in the error term

$$\nu_{it} = \xi_t + \eta_i + \varepsilon_{it}$$

which we identify by including first differences from years before 2001. Our main specification thus becomes

$$\Delta y_{it} = \alpha \Delta CCA_{it} + x_{it}' \beta + \xi_t + \eta_i + \varepsilon_{it}. \tag{2}$$

Least-squares estimation of equation (2) provides an unbiased estimate of the treatment effect α if ε_{it} is exogenous to CCA participation. The disturbance term ε_{it} reflects short-term deviations from a plant's idiosyncratic trend in energy consumption. Simultaneity of these shocks and CCA participation would induce bias in the estimate of α and may arise, for instance, if a plant's energy consumption is determined by the type and vintage of machinery it uses. In the presence of convex adjustment costs plants have an incentive to concentrate upgrades of their machinery at particular points in time. These "lumpy" upgrades would thus be associated with sudden drops in energy consumption. As a consequence, a plant that had scheduled an upgrade in 2001 for reasons unrelated to the introduction of the CCL package should have had a stronger incentive to join a CCA than a plant that was planning to invest only several years later.

5.3 Instrumental variable estimation

To further address the selection issue we propose an instrumental variable approach based on eligibility restrictions for CCA participation. As explained above, the government intended to base eligibility upon energy intensity, yet in practice granted eligibility to all qualifying part A activities under the PPC Act.[32] A dummy variable for whether or not a facility carries out such an activity is thus a good predictor of CCA participation. Further, this variable is a valid instrument if the polluting activity

[32]The reporting thresholds for the emitted pollutants also contained in PPC did not play a role when it came to determining eligibility for the reduced levy rate.

does not directly affect energy use. This should be true of plants that are covered by PPC regulations because they emit pollutants other than those resulting from combustion processes. When this instrument is used in the context of the difference equation (2) the identifying assumption is even less restrictive, in that being covered by the PPC act must be exogenous to a plant's specific trend deviation ε_{it} occurring after 2000.

For an illustration of the intuition behind this instrument consider the glass industry. Both the production and the recycling of glass containers are highly energy intensive processes. However, since only the former is pollution-intensive, glass container recycling was not eligible for CCA participation until the eligibility rules were revised in 2006.[33] Similarly, the eligibility rules for the British Apparel and Textile Confederation were amended in 2006 to include low pollution, high energy users that had previously been excluded from CCA participation. This institutional 'glitch' provides quasi-experimental variation in the probability of treatment.

To construct the instrumental variable, we downloaded publicly available data from the European Pollution Emissions Register (EPER) which covers all European facilities regulated under the IPPC directive whose emissions exceed the reporting thresholds. The 2001 EPER file contains reporting thresholds and pollution discharges into air and water for 50 pollutants and covers 2,397 facilities in 56 sectors of activity in the UK. The construction of the instrument involves two steps. First, using a detailed description of all substances regulated under IPPC, we identify all air pollutants for which the European Environmental Agency[34] lists a combustion or other energy intensive process as the main source of emissions. For example, combustion of coal is the main source of arsenic emissions, iron and steel production is the main source of cyanide emissions, and so on. We identify 31 air pollutants in this way.[35] Next, we construct the instrumental variable, *EPER*, as a dummy variable that is one if a facility reports emissions of any of the remaining 19 air pollutants or of the water pollutants regulated under IPPC. We assign a value of zero otherwise. Just like our treatment variable CCA, this variable is zero for all plants before 2001 and does not vary between 2002 and 2004. To match EPER facilities to plants in our data set we use the same algorithm that we used for CCA participation.

Econometrically, we perform a two-stage least squares estimation where the first stage is a regression of CCA participation on being listed in the EPER register because of water or non-combustion related air pollution

$$\Delta CCA_{it} = \tilde{\alpha} \Delta EPER_{it} + x'_{it}\tilde{\beta} + \tilde{\eta}_i + \tilde{\varepsilon}_{it} \tag{3}$$

and the second stage is a regression of outcome variables on predicted treatment indicators from the first stage

$$\Delta y_{it} = \alpha \Delta \widehat{CCA}_{it} + x'_{it}\beta + \eta_i + \varepsilon_{it} \tag{4}$$

[33] We thank John Stockdale of the British Glass Manufacturers' Confederation for pointing out this example to us.

[34] The description is available online at http://eper.eea.europa.eu/eper/pollutant_list.asp?.

[35] Specifically, we exclude methane, CO, CO2, N2O, NMVOC, NOx , PFC, SF6, sulfur oxides, nitrogen, arsenic, cadmium, chromium, copper, mercury, nickel, lead, zinc, hexachlorobenzene, dioxine and furane, benzene, BTEX, polycyclic aromatic hydrocarbons (PAH), phenlos, chloride, chlorine and inorganic compounds, cyanide, fluoride, fluorine and inorganic compounds, hydrogen cyanide, PM10 and toluene.

We also consider a reduced-form specification where we simply regress treatment on our instrument variable

$$\Delta y_{it} = \alpha \Delta EPER_{it} + x_{it}'\beta + \eta_i + \varepsilon_{it} \tag{5}$$

5.4 Heterogeneous impacts of taxation

So far we have implicitly assumed that α, the treatment effect, is constant across plants. If we drop this assumption and allow for the possibility of plant specific treatment effects, α_i, we have to carefully examine what kind of treatment effects we can estimate and how meaningful they are in the context of the issues we seek to address. Recently, an extensive debate in the treatment literature[36] has established that with heterogenous treatment effects the conventional instrumental variable estimator identifies a Local Average Treatment Effect (LATE), that is the average α for a subset of treated plants.[37]

It is likely that differences in treatment effects are even more pronounced *between* the groups of treated and non-treated plants than within those groups. This type of heterogeneity is particularly relevant when we try to quantify the possible impact of a modified CCL without discounts, because doing so necessitates an extrapolation of the estimated "treatment-on-treated" effect $\hat{\alpha}$ to non-treated plans. Assuming that there are two types of plants in the population,"treatment type" and "non-treatment type" plants, we can compute the expected aggregate effect Λ on outcome variable Y_i across plants i as a weighted mean of the individual treatment effects

$$\Lambda \sum_i Y_i \equiv \sum_i Y_i \left[\hat{\alpha} p_i + \tilde{\alpha}\left(1 - p_i\right)\right] \tag{6}$$

where the weight p_i is the proportion of "treatment type" plants in the population and $\tilde{\alpha}$ is the(average) treatment effect for "non-treatment type" plants. Since we cannot observe this counterfactual treatment, we proceed on the basis of the conservative assumption that $\tilde{\alpha} = 0$ for "non-treatment type" plants. Further, we substitute for p_i a propensity score of treatment based on observable plant characteristics. The score equals the predicted values from the probit regression

$$\mathbf{Pr}\left(CCA_i = 1\right) = f\left(x_{i2000}' \cdot \rho\right) \tag{7}$$

where x_{i2000} is a vector of pre-treatment plant characteristics and ρ is a parameter vector. Upon rewriting equation (6) we obtain an estimate of the average aggregate effect of a no-discount CCL on outcome variable Y_i given by

$$\hat{\Lambda} = \hat{\alpha} \frac{\sum_i \left(\hat{p}_i Y_i\right)}{\sum_i Y_i} \tag{8}$$

[36] See for example Imbens and Angrist (1994); Heckman (1999).

[37] In the diction of this literature, this is the subset of "compliers", i.e. plants that participate if and only if the instrumental variable takes a value of 1. To check the robustness of our results with respect to this type of heterogeneity, below we report regression results obtained in a sample of plants with "common support", as defined in Blundell et al. (2004).

where $\hat{p}_i$ is the predicted propensity score from equation (7).

6 The impacts of CCA participation on plant performance

6.1 The determinants of CCA participation

We start the review of our empirical results with an analysis of the determinants of CCA participation. We are particularly interested in the explanatory power of the instrumental variable *EPER* which indicates whether a plant is covered by PPC regulation due to emissions of water pollutants or of air pollutants other than those stemming from combustion activites. While PPC coverage is a legal precondition for CCA participation, it is also one of the formal requirements needed for our instrumental variable approach to be valid (see section 5.3 above). Furthermore we explore how various other plant characteristics correlate with CCA participation.

Table 7 reports various regressions of CCA participation. Each regression is run both on the sample with ARD data and on the sample with QFI data.[38] We start in columns 1 and 6 with a simple linear regression of CCA participation on *EPER* in a cross section for 2001. We see that PPC coverage proxied by *EPER* is a significant determinant of CCA participation. Columns 2 and 7 report the marginal effects from a probit regression of the same specification. The coefficients imply that a value of $EPER = 1$ increases a plant's chances of participating in a CCA by 38% in the ARD sample and by 60% in the QFI sample.

Next we run the linear regression in the full regression samples we use below. This corresponds to the first stage of the IV regression given by equation (3). The results are reported in columns 3 and 8 (with sector dummies) and in columns 4 and 9 (with plant fixed effects). The positive and significant coefficients in these columns confirm that *EPER* is a strong predictor of CCA participation.

Finally, columns 5 and 10 display the results from a probit regression for the 2001 cross section including various plant level controls for 2000. We shall use predicted values from this regression to compute propensity scores for the computation of equation (8) the results of which we report in section 6.4 below. The coefficient estimates largely confirm that the simple correlations we found in table 6 persist even when controlling for sectoral differences. In particular, plants that are larger in terms of their capital, labor and energy inputs are more likely to participate in a CCA. Interestingly, we obtain a negative coefficient on gross output. A plausible explanation for this is that *conditional on size* plants that expanded their output in the year before the CCL package was introduced were less inclined to participate in a CCA as an expansion would make it more difficult to meet their CCA target. In the next section we shall find further evidence for this type of selection bias.

[38] Here as in all other regressions reported below we dropped plants that report absolute changes of 100% or more in energy expenditures (i.e. the variable EE in the ARD sample and kWhE in the QFI sample). This is meant to limit the effect of outliers – such as an ARD reporting unit which closes down a local unit – on our estimate of the marginal effect of the tax discount.

6.2 Average treatment effect on CCA plants

Table 8 reports regression results for various outcome variables (in rows) under different assumptions about the error term ν_{it} (in columns). The first column contains results from a pooled OLS estimation of equation (2) without plant fixed effects. In column 2 we replace the CCA participation variable with the instrumental variable *EPER* to estimate the reduced-form equation (5). Column 3 reports results from a pooled two-stage least squares specification. Columns 4 to 6 repeat this sequence while including plant specific fixed effects η_i. Consequently, column 6 reports the most general estimate of the average treatment effect on the treated. We discuss the results for the various outcome variables in turn.

6.2.1 Energy

The first two panels of table 8 report the results for energy intensity measured as energy expenditures over gross output and as the share of energy expenditures in variable costs (the sum of expenditures on materials, energy and wages), respectively. The results are very similar for both variables. We find that plants in a CCA increased their energy intensity by more than 20% relative to plants that paid the full levy after 2000 (the point estimates from the fixed-effects IV regressions are 0.231 for the former measure and 0.284 for the latter). This effect is both economically and statistically significant. The point estimates change very little when moving to the regressions with fixed effects in columns 4 to 6. This suggests that normalizing energy use by some measure of plant size goes a long way to control for unobserved heterogeneity between plants. Further, the importance of controlling for selection is evident from the sizable differences between the OLS and IV estimates. In particular, OLS estimation leads to a downward bias when estimating the effect of CCA membership on the growth in energy intensity. A plausible explanation for this is that plants that expected a negative shock to energy intensity growth following the introduction of the CCL were more prone to seek membership in a CCA, expecting that it would be relatively easy for them to comply with a reduction target. This is consistent with the results from the probit regression presented above.

Panel 3 reports the results for energy expenditure. Here we only find a statistically significant and positive effect once we include fixed effects. This is an indication that there may have been declining trends in energy use *within* some 3-digit industries that are correlated with both CCA participation and EPER coverage. For instance, parts of the steel industry experienced a seminal downturn that coincided with the introduction of the CCL package, yet did not affect all quality tiers in steel production equally. Naturally, this issue disappears when dividing by a size control (as in panels 1 and 2) or when controlling for plant specific fixed effects (as in columns 4 to 6). The point estimate in the IV regression (column 6) implies that participation in a CCA led plants to increase their expenditures on energy by more than 15% relative to plants that were subject to the full tax.[39]

[39]One might ask what these estimates imply for the price elasticity of energy demand. Keeping in mind that the CCA discount amounts to a 10.4% reduction in energy cost paid by a typical business, the implicit price elasticity of energy expenditures can be computed as $\frac{0.151}{-0.104} = -1.45$. Assuming that the elasticity of after-tax energy prices with respect to the CCL is 1 the price elasticity of energy demand can be computed as $-1.45 - 1 = -2.45$. However, if tax-induced price changes are perceived as more permanent than other changes in the energy price then the IV procedure recovers an

6.2.2 Fuel substitution

The above results leave open the question whether CCL plants lowered their energy expenditures in a way that would be considered a success for climate change policy. A priori, this is not clear because this measure of energy use lumps together changes in the price and quantity of energy as well as the effects of substitution between different fuel types. For example, instead of consuming less of all fuel types CCL plants might substitute towards cheaper fuel sources which might also be more polluting, e.g. coal. To investigate this, the next seven panels in table 8 report results from regressions using *quantity* changes in energy consumption by fuel type which are available in the QFI sample. Although this sample is smaller than the ARD sample, we find economically and statistically significant evidence that CCA membership led plants to increase their electricity use by about 26%. This is in line with the design of the CCL which imposes the highest tax rate for electricity. For both gas and solid fuels (i.e. coal) we obtain negative point estimates on the CCA coefficient. We also find negative point estimates when looking at the share of these fuels in total kWh consumed. While these coefficients are not different from zero in a statistical sense, they hint at the possibility that some CCL plants switched from electricity to the lower taxed fuels gas and coal. This would also explain why the overall effect on total kWh is not significant in the IV regressions. If plants switch from electricity to gas or coal they are likely to require more kWhs of primary energy to achieve a given energy service. This could account for at least a partial offset of a tax-induced reduction in the demand for those services.

6.2.3 Carbon emissions

A significant increase in electricity consumption by CCA plants should translate into an increase in carbon emissions, given that we did not find a significant decline in the consumption of other fuel types. Next we examine whether we can find this effect when the outcome measure is the total sum of CO2 emissions across fuel types. The eleventh panel of table 8 reports that CCA membership is associated with a 5% increase in total CO2 emissions. The point estimate is very robust across specifications yet loses statistical significance in the IV regressions. It seems likely that this is due to the noise in the estimated response by fuels other than electricity. In the absence of a larger sample that would enable us to estimate this effect with more precision, we are left with two possible interpretations. On the one hand, we could disregard coefficients that are statistically insignificant at conventional levels altogether and conclude that the unchecked increase of electricity consumption translates into an increase in CO2 emissions of equal magnitude. On the other hand, a more cautious interpretation of our results would put the impact of CCA participation on carbon dioxide emissions at 5%, which accounts for the possibility that some CCL plants switched into dirtier fuels such as coal. We thus conclude that the full-rate CCL – though not designed as a pure carbon tax – led plants to reduce growth in CO2 emissions by between 5 and 26% more than the CCA targets did in combination with the discount on the levy.

estimate only of a tax-induced price change which is structurally different from that of other price changes (Davis and Kilian, 2009).

6.2.4 Economic performance

Finally, we investigate whether the impacts on energy consumption and energy efficiency that we find correspond to movements along the production isoquant or stem from significant shifts in the scale at which plants operate. In the 3 panels at the bottom of table 8 we look at various plant performance variables such as output, employment and total factor productivity (TFP).[40] When estimating the difference regression without fixed effects we obtain significantly negative coefficients for both employment and output. However, these effects disappear when we control for plant specific trends in columns 4 to 6. There are two things worth pointing out. First, a key policy concern with unilateral implementation of energy taxes is that they might jeopardize the competitiveness of domestic industry. If this was the case, we should observe positive employment or productivity effects of CCA participation because plants that pay the CCL scale down production and employment. Our finding of the opposite effect ought to dissipate such concerns. Second, the fact that the negative coefficients effects lose significance once we include plant fixed effects suggests that they are driven by pre-existing trends unrelated to the policy intervention. Similar to what occurred in the steel industry, this could be due to plants in industries covered by both CCA and PPC regulations which were on a declining trend even before the arrival of the CCL policy package. The last panel suggests that CCA participation had no discernible effect on total factor productivity. In sum, there is no evidence that the CCL had any adverse effects on economic outcome variables.

To summarize, our main specification provides robust evidence that the CCL discount has had a very pronounced effect on plant outcomes, leading to faster growth (or slower decline) in energy intensity in CCA plants relative to plants that paid the full CCL. Further, we find evidence that this was driven by a positive effect of CCA participation on energy use in CCA plants and not by a negative effect on economic performance. When looking at substitution between fuels we find evidence that CCA participation is associated with a faster growth (or slower decline) in electricity use which translates into a faster growth (or slower decline) in carbon emissions from these plants.

6.3 Robustness checks

6.3.1 The CCA treatment effect over time

In tables 9 and 10 we report results from an interaction of the CCA treatment coefficient with year dummies to examine how the treatment effect varies over the post-treatment years 2001 to 2004 which are available in our sample. The coefficients reveal the time profile of the CCA treatment effect and enable us to examine whether there were any time delays in plants' responses to the treatment, or whether the treatment effect dies off after a while.

Table 9 displays the annual treatment coefficients for the ARD variables. In terms of energy intensity (energy expenditure over gross output or variable costs) we see that there are strong CCA impacts

[40] To gauge the impact on TFP we augment equation (4) to include the production factors capital, labor, materials, and energy. This amounts to estimating a production function where the CCA coefficient captures the impact of CCA participation on otherwise unexplained differences in TFP. This approach controls for production function endogeneity that may arise from plant specific unobserved effects in levels and trends (Griliches and Mairesse, 1995).

present right from 2001 onwards. For energy expenditure over gross output these seem to decline slightly whereas for energy expenditure over variable costs there is a slight increase. These differences are, however, well within the margin of sampling error. For energy expenditure the effect appears strongest and most significant in the first year, 2001. The point estimates in later years are of similar magnitude although less significant. As was the case with the compound effects in table 8 table 9 contains no evidence of any effect on the economic performance variables employment, output and TFP.

In table 10 we turn to the energy quantity variables from the QFI. For electricity consumption the coefficients from 2002 onwards are large and significant, yet the coefficient for 2001 is small and statistically insignificant. Rather than a delayed response to the tax this could be due to the fact that the CCL was introduced on April 1st of 2001 and hence the treatment was only in place during the last three quarters of the first year. Interestingly, for gas consumption there is a negative and statistically significant effect in 2001 which quickly disappears thereafter. This might indicate that a short-term response by plants facing the full CCL rate was a shift towards gas as an alternative fuel but in the longer run these plants conserved on both electricity and gas.

6.3.2 Balanced sample

In the results above we include all available observations. Due to random sampling of smaller plants in the ARD, plant births and deaths as well as missing responses by some plants in some years our sample is essentially an unbalanced panel, i.e. we are looking at a slightly different set of plants from year to year. This implies that the time profile of the treatment effect might in part be driven by differences in sample composition and not just by actual differences over time within the same group of plants. Furthermore, the results could be dominated by potentially more extreme responses of exitors. We therefore re-estimate the model with time interactions in a subset of plants with valid observations in all years after 1999. The results are displayed in tables 11 and 12. The reduction of the QFI sample necessarily results in larger sampling error, and we see that some of the point estimates have changed. Overall, however, the qualitative conclusions from the previous sub-section are supported by this exercise.

6.3.3 Common support

As discussed in section 5.4, our IV estimate identifies a local average treatment effect. One approach to explore heterogenous treatment effects among the treated is to restrict the analysis to a sample with common support for the treatment and control group. Blundell et al. (2004) have proposed a framework for this which combines propensity score matching with an instrumental variable regression. Rather than using the whole sample of non-treated plants as a control group they suggest restricting the control group to a common support which is identified by the predicted probability of a plant in the control group to receive treatment. If the resulting estimates are very different from the ones obtained in the full sample then variations of treatment effects within the treated group are large and relevant. We implement this approach by running a probit regression of CCA participation on plant characteristics (as in columns 5 and 10 of table 7). We then re-estimate the full set of regressions including only those non-CCA plants in the control group that are within a certain range of the resulting propensity score distribution. Table 13 is analogous to table 8 but reports estimates obtained using only non-CCA plants that fall within the 10th to the 90th percentile band of the propensity score distribution. For the ARD variables this leads to very similar point estimates, suggesting that heterogeneity within the treated group is not a big problem. For energy quantities the point estimates are more different – in the case of electricity we obtain a CCA coefficient of 18% down from 26% – and most notably only significant at the 10 percent level. However, the difference in point estimates is within a 95% confidence interval and the reduced statistical significance appears to be driven by the reduced efficiency of the IV estimate in the much smaller sample.

6.4 Aggregate effects

The treatment effects we find above range from about 15% for energy expenditure (Panel 3, column 6 of table 8) to more than 25% for electricity.[41] As discussed in section 5.4, the interpretation of these effects is that they are the causal average treatment effects on the "treated type" of plant. There is thus no guarantee that a plant very dissimilar from the "treated type" would respond in a similar way. For a back-of-the-envelope calculation of a lower bound on the average effect for manufacturing as a whole we make the conservative assumption that the impact on "non treated type" plants is zero. As explained in section 5.4 this assumption allows us to compute the aggregate average effect by multiplying the treatment effects reported in table 8 with the propensity weighted share of the outcome variable in the aggregate, as in equation (8). Table 14 reports this value for a number of outcome variables. The propensity scores we are using are derived from the probit regression reported in column 5 of table 7. Applying this to the results in table 8 we find for energy expenditure

$$\Lambda_{EE} = 0.156 \times 0.59 = 9.2\%$$

and for electricity

$$\Lambda_{el} = 0.258 \times 0.65 = 16.8\%$$

Thus, had all plants in the manufacturing sector been paying the reduced rate we estimate that energy expenditures would have increased by at least 9.2% and electricity consumption by at least 16.8%. While it is important to further explore the drivers and nature of heterogeneity in the treatment effects in future work, there is strong evidence for a positive, statistically significant and economically meaningful positive effect of the reduced levy on energy consumption.

[41] Technically, the values in the tables are log points which only for small values are equivalent to percentage effects. For ease of comparing the discussion with the tables we stick to this interpretation here.

7 Discussion and conclusion

In this paper we have taken a novel approach to evaluating the effects of the UK Climate Change Levy and negotiated agreements by bringing to bear confidential business microdata on this issue. Previous research on this topic suffers from two main weaknesses. First, simulation studies are sensitive to the assumption of counterfactual baselines against which to calculate energy efficiency improvements attributable to the CCL or CCA. Second, econometric analysis using aggregate data does not allow for the identification of the causal effects of these policies.

To address these issues we have constructed a new dataset by matching data on CCA participation and energy use at the plant level to a large panel of manufacturing plants from the UK production census. The data allow us to circumvent the baseline problem by comparing changes in plant outcomes both over time and between plants that were subject to different energy tax rates. The baseline is hence given by the contemporaneous outcomes of plants that are not in a CCA. While we can only assess the "relative" effect of the CCA in this way, the benefit is that this assessment does not rely on any of the assumptions made in previous research regarding macroeconomic or sectoral trends in energy use. Moreover, our estimates of the impact of the CCA are purged of confounding factors that affect plant performance at the level of the economy, the region, the sector, and of unobserved differences in plant specific trends. Since we also control for self-selection into CCAs by exploiting exogenous variation in CCA eligibility rules in an instrumental variable regression framework, we can interpret our estimates as the causal effect of CCA participation on plant performance.

We find robust evidence that CCA participation had a statistically significant positive impact on growth in energy intensity, energy expenditure and electricity consumption. In our most general specification, the treatment effects on CCA plants are economically significant and range from 15% for energy expenditure to between 23% and 29% for energy intensity and electricity use. From this we conclude that the price incentive provided by the CCL led to stronger reductions in energy consumption than the energy efficiency or consumption targets imposed by the CCA. If these targets are not binding, our estimates recover the full impact of the tax disount, otherwise they can be interpreted as a lower bound. The strong effect on electricity consumption is consistent with the fact that the CCL imposes the highest tax rate on this fuel type. Since we do not find evidence of significant reductions in the consumption of other fuels, we conclude that CCA participation had a positive impact on CO2 emission growth on the range of at least 5% and up to 26%.

An argument often presented in favor of the CCA tax discount is that unilateral implementation of a significant energy tax could jeopardize the competitiveness of energy intensive UK firms in international product markets. We have investigated this empirically and find neither a discernible loss of jobs, nor a decline in output or productivity for the average plant paying the full tax rate. Hence we conclude that the tax discount granted to plants in a CCA cannot be justified as a means to mitigate negative impacts on economic performance arising from the CCL.

On balance, our results support a strong case for the introduction of moderate energy taxes to encourage electricity conservation, to improve energy efficiency and to curb greenhouse gas emissions in the manufacturing sector. This is in contrast to previous research that attributed substantial carbon savings to the CCA scheme on the basis of comparisons with counterfactual baseline emissions (Ekins and Etheridge, 2006; Barker et al., 2007; AEAT, 2004).[42] An interesting question arising from this analysis is whether alternative measures of putting a price on carbon emissions would have led to similar results. For instance, a carbon trading system such as the UK ETS or the EU ETS can sustain meaningful prices *provided that* the underlying cap on emissions puts binding constraints on business energy use. At least in this specific case, however, neither previous research (Cambridge Econometrics, 2005) nor our own finds evidence that the targets negotiated under the CCA were indeed stringent, and the consistently low prices in the UK ETS speak to this as well (Smith and Swierzbinski, 2007). Therefore, we prefer to stick to a narrow interpretation of our results and maintain that further cuts in energy use and carbon emissions of substantial magnitude could have been achieved without negative impacts on economic performance, had the CCL been implemented at full rate for all businesses.

This study has taken a first step towards building an evidence base using plant level data to inform policymakers about the impacts of climate change policies on the business sector. As more and more such policies are implemented across countries, and as business microdata become more abundant and easier to access, we expect that researchers will exploit the variation in policies and institutional settings to make further interesting contributions to this evidence base. In the particular context of climate change policy in the UK, there are several issues that deserve attention in future research. First, it seems important to gain a better understanding of how plants achieved the substantial reductions in energy use that we measure. Knowledge of the key drivers of energy conservation – be they technical, economic or managerial – will facilitate the design of more sophisticated policies that achieve reductions in carbon emissions at minimal cost to business. From a political economy point-of-view, a thorough analysis of the bargaining process in the settting of CCA targets and of compliance behaviour of individual CCA facilities should provide important insights for the design of negotiated agreements. Finally, given the long-term nature of climate change, an important open question is whether a moderate energy tax such as the CCL can stimulate sufficient innovation to bring about substantial carbon reductions in the future.

[42]This finding contrasts as well with results obtained by Bjorner and Jensen (2002) who investigate the consequences of a similar policy package in Denmark and obtain a positive effect of negotiated agreements on energy efficiency. Institutional differences between the British and the Danish policy packages aside, their finding might be due in part to the fact that they attempt to identify both a price and a quantity effect of the negotiated agreements. Moreover, these authors do not control for selection into negotiated agreements based on time-varying unobservable variables.

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A Tables

Table 1: Taxation of energy and implicit carbon by fuel type

fuel type	tax rate [$\frac{\text{pence}}{\text{kWh}}$]	fuel price [$\frac{\text{pence}}{\text{kWh}}$]	implicit carbon tax [$\frac{£}{\text{tC}}$]
electricity	0.43	4.25	31
coal	0.15	2.46	16
gas	0.15	0.91	30
LPG	0.07	0.85	22

Notes: Average fuel prices in 2001 based on QFI sample.
Carbon prices taken from Pearce (2006).

Table 2: Sectoral Climate Change Agreements and targets

	(1)	(2)	(3)	(4)
Sectors		**TP 1**	**TP 2**	**TP 3**
	Sector Target	**# TU**	**# TU**	**# TU**
Aerospace	Abs E	11	17	24
Agricultural Supply	Rel E	165	152	137
Aluminium	Rel C	57	34	50
Apparel & Textile I	Rel E	155	131	100
Apparel & Textile II	Rel E			12
Bakers	Rel E	380	328	299
Brewers	Rel E	66	60	48
Calcium Carbonate	Rel E			<10
Cathode Ray Tube	Rel E	<10	.	.
Cement Slag	Rel E		<10	<10
Cement	Rel E	<10	<10	<10
Ceramic	Rel E	124	117	114
Chemical	Rel E	279	243	234
Clay	Abs E			<10
Industrial Gases	Rel E			<10
Dairy	Rel E	152	120	101
Eggs	Rel E	10	<10	<10
Eggs Farming	Rel E	311	174	142
Food & Drink	Rel E	923	896	830
Foundries	Rel E	235	188	174
Geosynthetics	Rel E			<10
Glass Manufacturing	Rel E			15
Gypsum	Rel E	<10	<10	<10
Heat Treatment	Rel E			50
Horticulture	Rel E			121
Leather	Rel E	12	11	<10
Lime	Rel E	<10	<10	<10
Maltsters	Rel E	25	24	21
Metal Forming	Rel E	103	98	84
Metal Packaging	Rel C	20	22	21
Motors	Rel E	12	20	25
Non Ferrous Alliance	Rel E		78	75
Packaging	Rel C			16
Pig Farming	Rel E	612	349	297
Poultry Meat Farming	Rel E	253	182	159
Poultry Meat Production	Rel E	80	71	63
Poultry Farming	Rel E	549	402	359
Printing	Rel E	103	121	150
Red Meat Production	Rel E	145	147	155
Renderers	Rel E	16	12	13
Rubbers	Rel E	<10	<10	<10
Semi Conductor	Rel E	16	23	28
Spirits	Rel E	24	26	25
Steel	Abs E	<10	20	21
Supermarkets	Abs E	<10	<10	<10
Surface Engineering	Rel E	179	191	206
Wallcovering	Abs E	15	10	11
Wood	Rel E	<10	<10	10
Total		5,108	4,319	4,262

Notes: Rel=relative target, Abs=absolute target, C=carbon, E=energy, TP=target period, TU= target unit.

Table 3: Descriptive statistics - ARD sample

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Variables	**mean**	**sd**	**sd, between**	**sd,within**	**p10**	**p90**	**N obs**
Age	14.20	9.58	8.92	1.14	3.00	29.00	54,078
Employment (L)	180.76	489.96	386.16	126.90	8.00	407.00	54,078
Gross Output (GO)	25.44	123.77	95.48	27.28	0.35	45.20	54,078
Variable Costs (Vcost)	21.80	107.15	80.53	26.12	0.26	39.45	54,078
Capital Stock (K)	15.84	86.57	67.60	6.43	0.14	29.16	52,494
Energy Expenditures (EE)	0.41	2.97	2.67	0.63	0.00	0.64	53,650
EE over GO (EE/GO %)	1.58	1.27	1.20	0.43	0.44	3.07	47,559
EE over Vcost (EE/VCost %)	1.95	1.57	1.55	0.51	0.57	3.73	47,559

Notes: Descriptive statistics for the ARD pooled sample (1999-2004)
The variables GO, K, Vcost and EE are in thousands of pounds.

Table 4: Descriptive statistics - QFI sample

Variables	(1) mean	(2) sd	(3) sd, between	(4) sd,within	(5) p10	(6) p90	(7) N obs
Electricity (El)	13,570.45	50,803.78	58,280.98	8,285.08	350.17	26,274.92	5,521
Electricity Expenditures (ElE)	406.81	1,306.07	1,491.93	205.84	17.30	821.81	5,521
Liquid Fuels (Li)	0.57	7.57	6.73	1.14	0.00	0.00	5,521
Liquid Fuels Expenditures (LiE)	35.78	434.39	414.52	67.03	0.00	0.00	5,521
Gas (Gas)	27,635.74	135,419.71	132,196.10	36,953.70	0.00	47,623.43	5,511
Share of Gas over Gas and El Consumption (Gas/(Gas+El))	0.24	0.20	0.19	0.08	0.00	0.52	5,487
Gas Exp. (GasE)	201.31	939.64	861.76	289.11	0.00	352.16	5,521
Share of Gas over Gas and El Expenditures (GasE/(GasE+ElE))	0.46	0.30	0.29	0.10	0.00	0.82	5,487
Solid Fuels (So)	0.38	5.20	6.79	1.42	0.00	0.36	5,521
Solid Fuels Expenditures (SoE)	51.43	573.91	746.03	144.53	0.00	63.97	5,521
Total kWh (kWh)	49,992.84	219,778.46	240,000.00	41,300.00	929.49	82,506.86	5,521
Total kWh Expenditures (kWhE)	692.13	2,410.12	2,679.24	372.24	26.62	1,331.08	5,521
CO2 (CO2)	18,579.60	74,992.96	84,091.85	12,085.18	428.39	32,086.12	5,521
CO2 over total kWh (CO2/kWh)	0.45	0.13	0.13	0.05	0.30	0.67	5,521

Notes: Descriptive statistics for the QFI pooled sample (1999-2004) GO and all the expenditure variables are in thousands of pounds. Total kWh, Gas and El are in thousands of kWh. So and Li are in thousands of tonnes. The CO2 variable measures total CO2 emissions in thousands of tonnes based on fuel use (the conversion factors are from the Entech Utility Service Bureau, for more details see Martin 2006).

Table 5: Descriptive statistics - ARD-QFI joint sample

Variables	(1) mean	(2) sd	(3) sd, between	(4) sd,within	(5) p10	(6) p90	(7) N obs
Electricity (El)	17,411.14	53,354.97	44,439.77	10,111.78	550.61	38,122.57	3,614
Electricity Expenditures (ElE)	518.81	1,364.78	1,150.48	244.60	25.66	1,190.39	3,614
Liquid Fuels (Li)	0.74	8.59	7.42	1.37	0.00	0.00	3,614
Liquid Fuels Expenditures (LiE)	46.41	500.32	466.05	71.99	0.00	0.00	3,614
Gas (Gas)	36,396.56	154,114.30	119,049.80	45,320.24	0.00	65,819.65	3,608
Share of Gas over Gas and El Consumption (gas/(gas+el))	0.25	0.20	0.19	0.07	0.00	0.53	3,597
Gas Expenditures (GasE)	267.71	1,108.01	847.58	352.83	0.00	517.79	3,614
Share of Gas over Gas and El Expenditures (GasE/(GasE+ElE))	0.47	0.30	0.29	0.09	0.00	0.82	3,597
Solid Fuels (So)	0.41	4.99	5.50	1.59	0.00	0.49	3,614
Solid Fuels Expenditures (SoE)	58.13	577.63	638.67	175.92	0.00	78.60	3,614
Total kWh (kWh)	64,265.10	231,896.29	196,818.80	49,477.93	1,490.49	121,507.90	3,614
Total kWh Expenditures (kWhE)	887.35	2,553.34	2,216.24	448.23	40.05	1,890.61	3,614
Total kWh over GO (kWh/GO)	0.02	0.02	0.02	0.00	0.00	0.04	3,034
CO2 (CO2)	23,791.86	77,904.14	67,160.30	14,456.08	679.42	46,653.24	3,614
CO2 over total kWh (CO2/kWh)	0.45	0.13	0.13	0.05	0.30	0.67	3,614
CO2 over GO (CO2/GO)	444.15	678.87	645.06	120.53	48.75	1,071.94	3,614

Notes: Descriptive statistics for QFI variables in the joint sample of firms with lnGO not missing, pooled for 1999-2004. All the expenditure variables are in thousands of pounds. Total kWh, Gas and El are in thousands of kWh. So and Li are in thousands of tonnes. The CO2 variable measures total CO2 emissions in thousands of tonnes based on fuel use (the conversion factors are from the Entech Utility Service Bureau, for more details see Martin 2006).

Table 6: Descriptive statistics by CCA participation status

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Data set		**ARD**			**QFI**			**QFI and ARD**	
Variables	**CCA=0**	**CCA=1**	**diff test**	**CCA=0**	**CCA=1**	**diff test**	**CCA=0**	**CCA=1**	**diff test**
Age	13.55	17.53	***	21.86	22.87	-	21.54	22.84	*
Employment (L)	151.49	536.44	***	372.05	548.98	***	373.14	548.98	***
Gross Output (GO)	19.08	86.08	***	49.07	91.56	***	49.29	91.56	***
Energy Expenditures (EE)	0.22	1.95	***	0.59	3.79	***	0.59	3.79	***
Variable Costs (Vcost)	15.99	75.14	***	42.19	78.46	***	42.39	78.46	***
Capital Stock (K)	9.64	58.17	***	23.12	65.44	***	28.89	72.78	***
EE over Variable Costs (EE/Vcost)	1.92	3.01	***	1.99	3.60	***	1.99	3.60	***
Electricity (El)	8,701.55	38,191.39	***	8,888.03	34,210.84	***	8,701.55	38,191.39	***
Electricity Expenditures (ElE)	306.93	1,162.83	***	292.64	1,050.91	***	306.93	1,162.83	***
Gas (Gas)	14,144.07	75,098.82	***	14,859.74	68,213.13	***	14,144.07	75,098.82	***
Share of Gas over Gas and El Consumption (Gas/(Gas+El))	0.19	0.24	***	0.18	0.25	***	0.19	0.24	***
Solid Fuels (So)	0.01	0.34	-	0.39	1.44	-	0.21	1.66	-
Solid Fuels Expenditures (SoE)	1.91	44.30	*	55.98	191.24	-	36.42	219.43	-
Liquid Fuels (Li)	0.01	0.36	-	0.21	2.02	*	0.28	1.78	-
Liquid Fuels Expenditures (LiE)	0.71	20.45	**	10.74	132.41	**	13.52	101.28	*
Total kWh (kWh)	27,261.95	146,775.90	***	29,834.32	135,378.51	***	27,261.95	146,775.90	***
Total kWh Expenditures (kWhE)	23.23	390.91	***	446.06	1,784.71	***	443.30	1,936.10	***
Total kWh over GO (kWh/GO)	0.01	0.03	***	0.01	0.03	***	0.01	0.03	***
CO2 (CO2)	10,673.51	54,239.67	***	11,454.80	50,219.85	***	10,673.51	54,239.67	***
CO2 over total kWh (CO2/kWh)	0.45	0.44	-	0.45	0.43	*	0.45	0.44	-
CO2 over GO (CO2/GO)	326.82	750.21	***	326.82	750.21	***	326.82	750.21	***
Number of Plants	8,282	1,050		701	251		434	212	

Notes: Variables in 2000 by CCA status GO and all the expenditure variables are in thousands of pounds. Total kWh, Gas and El are in thousands of kWh. So and Li are in thousands of tonnes. The CO2 variable measures total CO2 emissions in thousands of tonnes based on fuel use (the conversion factors are from the Entech Utility Service Bureau, for more details see Martin 2006). Columns 3, 6, and 9 report significance levels from a *t* test of differences in group means with unequal variance, at ≤1% (***), ≤5% (**), ≤10% (*)

Table 7: First stage regression

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Dep.Variable	**CCA participation**									
Sample	**ARD sample**					**QFI sample**				
Time period	**2001**	**2001**	**2000-2004**	**2000-2004**	**2001**	**2001**	**2001**	**1998-2004**	**1998-2004**	**2001**
Method	**OLS**	**Probit**	**OLS**	**FE**	**Probit**	**OLS**	**Probit**	**OLS**	**FE**	**Probit**
EPER	0.411***	0.383***	0.391***	0.480***		0.433***	0.609***	0.414***	0.497***	
	(0.030)	(0.044)	(0.033)	(0.040)		(0.069)	(0.076)	(0.062)	(0.061)	
lnGO(t-1)					-0.014***					-0.043
					(0.004)					(0.067)
lnK(t-1)					0.016***					0.222***
					(0.003)					(0.056)
lnEE(t-1)					0.020***					0.057
					(0.003)					(0.040)
lnL(t-1)					0.011***					-0.031
					(0.003)					(0.059)
age controls	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
sector controls	yes	yes	yes	no	yes	yes	yes	yes	no	yes
region X year controls	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
plant fixed effects	no	no	no	yes	no	no	no	no	yes	no
obs	9175	8506	17040	17040	8456	922	735	4578	4578	478

Notes: Probit results report the marginal effects on the probability of being in a CCA. Standard errors in parenthesis.

Table 8: Effects of CCA membership

DepVar	ExpVar	(1) OLS	(2) Reduced Form (OLS)	(3) IV	(4) Fixed Effects	(5) Reduced Form (FE)	(6) Fixed Effects IV	(7) Obs./ Plants
Energy exp. over gross output	CCA/EPER	0.026**	0.086***	0.220***	0.025	0.111***	0.231***	14,336
Δln(EE/GO)		(0.013)	(0.028)	(0.072)	(0.019)	(0.040)	(0.084)	4,209
Energy exp. over variable costs	CCA/EPER	0.026**	0.104***	0.266***	0.015	0.137***	0.285***	14,336
Δln(EE/VCost)		(0.012)	(0.026)	(0.069)	(0.018)	(0.037)	(0.080)	4,209
Energy exp.	CCA/EPER	0.019	0.033	0.085	0.036**	0.075**	0.156**	14,336
Δln(EE)		(0.012)	(0.024)	(0.061)	(0.017)	(0.029)	(0.061)	4,209
Total kWh	CCA/EPER	0.068**	-0.000	-0.001	0.079**	-0.004	-0.007	4,452
Δln(kWh)		(0.027)	(0.049)	(0.115)	(0.035)	(0.068)	(0.135)	928
Electricity	CCA/EPER	0.026	0.085*	0.206*	0.028	0.128**	0.258**	4,452
Δln(El)		(0.021)	(0.046)	(0.118)	(0.024)	(0.058)	(0.127)	926
Gas	CCA/EPER	0.016	0.014	0.036	0.012	-0.035	-0.066	3,602
Δln(Gas)		(0.037)	(0.052)	(0.127)	(0.047)	(0.080)	(0.151)	764
Share of gas over gas & elec. cons.	CCA/EPER	0.018**	-0.044	-0.107	0.022**	-0.048	-0.097	4,435
Δ(Gas/(Gas+El))		(0.008)	(0.031)	(0.078)	(0.009)	(0.039)	(0.084)	926
Share of gas over kWh	CCA/EPER	0.013	-0.007	-0.018	0.018	-0.010	-0.021	4,449
Δ(Gas/kWh)		(0.011)	(0.023)	(0.055)	(0.015)	(0.032)	(0.065)	928
Solid fuels	CCA/EPER	-0.155	-0.226	-0.649	-0.091	-0.290	-0.542	1,467
Δln(So)		(0.101)	(0.224)	(0.597)	(0.115)	(0.266)	(0.486)	344
Solid fuels over kWh	CCA/EPER	0.003	-0.016	-0.039	0.005	-0.022	-0.044	4,452
Δ(So/kWh)		(0.004)	(0.011)	(0.025)	(0.006)	(0.015)	(0.030)	928
CO2	CCA/EPER	0.050**	0.018	0.044	0.053**	0.024	0.048	4,452
Δln(CO2)		-0.021	-0.040	-0.094	-0.026	-0.051	-0.101	928
Employment	CCA/EPER	-0.014	-0.039*	-0.101*	0.021	-0.019	-0.041	14,336
Δln(L)		(0.011)	(0.021)	(0.054)	(0.014)	(0.036)	(0.075)	4,209
Real gross output	CCA/EPER	-0.008	-0.053**	-0.136**	0.011	-0.036	-0.076	14,336
Δln(Real GO)		(0.011)	(0.022)	(0.057)	(0.014)	(0.035)	(0.072)	4,209
Total Factor	CCA/EPER	-0.002	0.000	0.001	-0.007	0.009	0.018	14,288
Productivity		(0.006)	(0.015)	(0.038)	(0.009)	(0.026)	(0.054)	4,194
Δln(GO)	Δln(M)	0.477***	0.477***	0.477***	0.468***	0.469***	0.468***	
		(0.013)	(0.013)	(0.013)	(0.017)	(0.017)	(0.017)	
	Δln(EE)	0.034***	0.034***	0.034***	0.036***	0.036***	0.036***	
		(0.006)	(0.006)	(0.006)	(0.008)	(0.008)	(0.007)	
	Δln(L)	0.257***	0.257***	0.257***	0.237***	0.237***	0.237***	
		(0.013)	(0.013)	(0.013)	(0.018)	(0.018)	(0.018)	
	Δln(K)	0.049***	0.049***	0.049***	0.069***	0.068***	0.068***	
		(0.016)	(0.016)	(0.016)	(0.020)	(0.020)	(0.020)	

Notes: Dependent variables are first-differenced from 1997 until 2000 and differenced at various intervals thereafter. Column 1 displays OLS coefficient, column 2 displays OLS coefficient on the instrumental variable in the reduced form, and column 3 displays the 2-stage least squares estimate. Columns 4 to 6 have the same setup while including a firm fixed effect. Column 7 reports the number of observations. All regressions include age, age squared, year dummies and region-by-year dummies. Columns 1 to 3 in addition include region and 3-digit industry dummies.

Table 9: Effects of CCA membership by year - ARD outcome variables

		(1)	(2)	(3)	(4)	(5)	(6)	(7)
DepVar	**ExpVar**	**OLS**	**Reduced Form (OLS)**	**IV**	**Fixed Effects**	**Reduced Form (Fixed effects)**	**Fixed Effects IV**	**Obs./ Plants**
Energy exp. over gross output	CCA/EPERxY2001	0.034**	0.099***	0.243***	0.033*	0.120***	0.255***	14,351
		(0.014)	(0.025)	(0.062)	(0.019)	(0.038)	(0.081)	4,212
Δln(EE/GO)	CCA/EPERxY2002	0.009	0.077**	0.211**	0.006	0.102**	0.213**	
		(0.017)	(0.037)	(0.092)	(0.021)	(0.046)	(0.097)	
	CCA/EPERxY2003	0.008	0.055	0.157*	0.011	0.103**	0.212**	
		(0.019)	(0.041)	(0.094)	(0.023)	(0.048)	(0.099)	
	CCA/EPERxY2004	0.058***	0.113**	0.267***	0.053**	0.112**	0.230**	
		(0.020)	(0.045)	(0.098)	(0.024)	(0.052)	(0.105)	
Energy exp. over variable costs	CCA/EPERxY2001	0.023*	0.100***	0.255***	0.014	0.131***	0.277***	14,351
		(0.013)	(0.024)	(0.061)	(0.019)	(0.036)	(0.080)	4,212
Δln(EE/VCost)	CCA/EPERxY2002	0.016	0.095***	0.259***	0.004	0.133***	0.277***	
		(0.016)	(0.035)	(0.089)	(0.020)	(0.043)	(0.092)	
	CCA/EPERxY2003	0.013	0.079**	0.215**	0.005	0.128***	0.263***	
		(0.018)	(0.040)	(0.091)	(0.022)	(0.045)	(0.095)	
	CCA/EPERxY2004	0.055***	0.154***	0.354***	0.048**	0.161***	0.328***	
		(0.020)	(0.042)	(0.093)	(0.023)	(0.048)	(0.098)	
Energy exp. Δln(EE)	CCA/EPERxY2001	0.018	0.052**	0.120**	0.031*	0.089***	0.189***	14,351
		(0.013)	(0.023)	(0.055)	(0.018)	(0.030)	(0.064)	4,212
	CCA/EPERxY2002	-0.004	0.007	0.035	0.020	0.063*	0.131*	
		(0.017)	(0.033)	(0.080)	(0.020)	(0.036)	(0.074)	
	CCA/EPERxY2003	0.014	-0.001	0.017	0.034	0.053	0.111	
		(0.018)	(0.034)	(0.077)	(0.021)	(0.036)	(0.072)	
	CCA/EPERxY2004	0.053***	0.071*	0.155*	0.075***	0.074*	0.152*	
		(0.019)	(0.041)	(0.089)	(0.023)	(0.043)	(0.084)	
Employment Δln(L)	CCA/EPERxY2001	-0.027**	-0.031*	-0.083*	0.005	-0.015	-0.031	14,351
		(0.012)	(0.018)	(0.045)	(0.013)	(0.033)	(0.070)	4,212
	CCA/EPERxY2002	-0.020	-0.034	-0.096*	0.021	-0.006	-0.013	
		(0.013)	(0.022)	(0.055)	(0.015)	(0.034)	(0.070)	
	CCA/EPERxY2003	0.011	-0.067	-0.153	0.039**	-0.045	-0.089	
		(0.015)	(0.044)	(0.098)	(0.017)	(0.054)	(0.109)	
	CCA/EPERxY2004	-0.014	-0.037	-0.095	0.027	-0.027	-0.053	
		(0.017)	(0.033)	(0.070)	(0.019)	(0.045)	(0.089)	
Real gross output	CCA/EPERxY2001	-0.015*	-0.047***	-0.123***	-0.002	-0.031	-0.066	14,351
		(0.009)	(0.018)	(0.044)	(0.013)	(0.031)	(0.066)	4,212
Δln(Real GO)	CCA/EPERxY2002	-0.013	-0.069***	-0.176***	0.014	-0.039	-0.082	
		(0.013)	(0.026)	(0.066)	(0.016)	(0.036)	(0.076)	
	CCA/EPERxY2003	0.006	-0.056*	-0.140*	0.023	-0.050	-0.101	
		(0.015)	(0.033)	(0.075)	(0.017)	(0.042)	(0.085)	
	CCA/EPERxY2004	-0.005	-0.042	-0.112	0.022	-0.038	-0.078	
		(0.018)	(0.044)	(0.093)	(0.019)	(0.050)	(0.101)	
Total Factor Productivity	CCA/EPERxY2001	-0.006	-0.010	-0.021	-0.012	0.001	0.002	14,303
		(0.006)	(0.011)	(0.027)	(0.009)	(0.022)	(0.047)	4,197
Δln(GO)	CCA/EPERxY2002	0.000	-0.009	-0.018	-0.002	0.006	0.013	
		(0.008)	(0.018)	(0.045)	(0.011)	(0.028)	(0.059)	
	CCA/EPERxY2003	0.003	0.011	0.022	-0.005	0.008	0.017	
		(0.009)	(0.021)	(0.048)	(0.011)	(0.031)	(0.063)	
	CCA/EPERxY2004	-0.005	0.019	0.038	-0.003	0.026	0.050	
		(0.010)	(0.026)	(0.058)	(0.012)	(0.035)	(0.071)	
	Δln(M)	0.478***	0.478***	0.478***	0.469***	0.469***	0.469***	
		(0.013)	(0.013)	(0.013)	(0.017)	(0.017)	(0.017)	
	Δln(EE)	0.034***	0.034***	0.034***	0.037***	0.036***	0.036***	
		(0.006)	(0.006)	(0.006)	(0.008)	(0.008)	(0.008)	
	Δln(L)	0.256***	0.256***	0.256***	0.236***	0.236***	0.236***	
		(0.013)	(0.013)	(0.013)	(0.018)	(0.018)	(0.018)	
	Δln(K)	0.049***	0.049***	0.048***	0.068***	0.068***	0.066***	
		(0.016)	(0.016)	(0.016)	(0.020)	(0.020)	(0.020)	

Notes: Dependent variables are first-differenced from 1997 until 2000 and differenced at various intervals thereafter. Column 1 displays OLS coefficient, column 2 displays OLS coefficient on the instrumental variable in the reduced form, and column 3 displays the 2-stage least squares estimate. Columns 4 to 6 have the same setup while including a firm fixed effect. Column 7 reports the number of observations. All regressions include age, age squared, year dummies and region-by-year dummies. Columns 1 to 3 in addition include region and 3-digit industry dummies.

Table 10: Effects of CCA membership by year - QFI outcome variables

		(1)	(2)	(3)	(4)	(5)	(6)	(7)
DepVar	**ExpVar**	**OLS**	**Reduced Form (OLS)**	**IV**	**Fixed Effects**	**Reduced Form (FE)**	**Fixed Effects IV**	**Obs./ Plants**
Total kWh	CCA/EPERxY2001	0.065***	-0.029	-0.069	0.076**	-0.055	-0.127	4,452
Δln(kWh)		(0.024)	(0.055)	(0.136)	(0.031)	(0.067)	(0.146)	928
	CCA/EPERxY2002	0.082**	0.006	0.011	0.093**	-0.004	-0.010	
		(0.036)	(0.084)	(0.178)	(0.042)	(0.100)	(0.192)	
	CCA/EPERxY2003	0.095**	0.040	0.087	0.102**	0.054	0.120	
		(0.037)	(0.061)	(0.138)	(0.043)	(0.074)	(0.152)	
	CCA/EPERxY2004	0.026	-0.013	-0.029	0.037	0.007	0.015	
		(0.043)	(0.067)	(0.147)	(0.048)	(0.072)	(0.147)	
Electricity	CCA/EPERxY2001	0.011	0.020	0.068	0.015	0.043	0.064	4,435
Δln(El)		(0.018)	(0.041)	(0.106)	(0.021)	(0.045)	(0.094)	926
	CCA/EPERxY2002	0.038	0.136**	0.297**	0.034	0.159**	0.304**	
		(0.025)	(0.057)	(0.132)	(0.027)	(0.069)	(0.142)	
	CCA/EPERxY2003	0.030	0.125**	0.289*	0.035	0.195***	0.408**	
		(0.029)	(0.063)	(0.158)	(0.031)	(0.069)	(0.165)	
	CCA/EPERxY2004	0.028	0.074	0.171	0.031	0.144*	0.292*	
		(0.034)	(0.072)	(0.167)	(0.035)	(0.074)	(0.170)	
Gas	CCA/EPERxY2001	-0.011	-0.083	-0.174	-0.002	-0.143**	-0.310**	3,602
Δln(Gas)		(0.036)	(0.063)	(0.142)	(0.043)	(0.073)	(0.148)	764
	CCA/EPERxY2002	0.059	0.142*	0.321*	0.055	0.083	0.193	
		(0.046)	(0.074)	(0.165)	(0.053)	(0.097)	(0.177)	
	CCA/EPERxY2003	0.044	0.024	0.062	0.040	-0.016	-0.024	
		(0.052)	(0.087)	(0.213)	(0.060)	(0.113)	(0.239)	
	CCA/EPERxY2004	-0.033	-0.002	-0.001	-0.056	-0.028	-0.050	
		(0.060)	(0.073)	(0.175)	(0.066)	(0.091)	(0.189)	
Share of gas over kWh	CCA/EPERxY2001	0.004	-0.017	-0.042	0.009	-0.024	-0.053	4,449
		(0.009)	(0.020)	(0.053)	(0.013)	(0.027)	(0.057)	928
Δ(Gas/kWh)	CCA/EPERxY2002	0.024	0.005	0.008	0.030	0.003	0.006	
		(0.015)	(0.028)	(0.061)	(0.018)	(0.036)	(0.068)	
	CCA/EPERxY2003	0.025*	-0.010	-0.024	0.027	-0.012	-0.024	
		(0.014)	(0.027)	(0.063)	(0.017)	(0.036)	(0.075)	
	CCA/EPERxY2004	0.001	-0.004	-0.009	0.005	-0.003	-0.006	
		(0.018)	(0.031)	(0.068)	(0.021)	(0.040)	(0.083)	
Solid fuels	CCA/EPERxY2001	-0.065	-0.091	-0.320	0.035	-0.133	-0.227	1,467
Δln(So)		(0.105)	(0.204)	(0.508)	(0.120)	(0.261)	(0.524)	344
	CCA/EPERxY2002	-0.209*	-0.096	-0.464	-0.122	-0.259	-0.471	
		(0.112)	(0.268)	(0.734)	(0.124)	(0.277)	(0.483)	
	CCA/EPERxY2003	-0.227	-0.629	-1.468	-0.234	-0.679	-1.363	
		(0.171)	(0.446)	(1.024)	(0.169)	(0.452)	(0.860)	
	CCA/EPERxY2004	-0.166	-0.201	-0.534	-0.154	-0.351	-0.637	
		(0.187)	(0.506)	(1.108)	(0.182)	(0.508)	(0.961)	
Solid fuels over kWh	CCA/EPERxY2001	0.012***	0.001	-0.002	0.014**	-0.002	0.001	4,452
		(0.004)	(0.011)	(0.026)	(0.005)	(0.013)	(0.026)	928
Δ(So/kWh)	CCA/EPERxY2002	-0.004	-0.038*	-0.081*	-0.002	-0.043	-0.083	
		(0.006)	(0.022)	(0.045)	(0.007)	(0.027)	(0.051)	
	CCA/EPERxY2003	0.003	-0.020	-0.047	0.004	-0.028*	-0.057*	
		(0.006)	(0.013)	(0.031)	(0.007)	(0.016)	(0.033)	
	CCA/EPERxY2004	-0.001	-0.012	-0.028	0.002	-0.021	-0.041	
		(0.005)	(0.012)	(0.026)	(0.006)	(0.014)	(0.029)	
CO2	CCA/EPERxY2001	0.042**	-0.019	-0.041	0.047**	-0.036	-0.091	4,452
Δln(CO2)		(0.019)	(0.048)	(0.116)	(0.023)	(0.052)	(0.114)	928
	CCA/EPERxY2002	0.062**	0.038	0.081	0.064**	0.036	0.067	
		(0.026)	(0.059)	(0.125)	(0.030)	(0.069)	(0.132)	
	CCA/EPERxY2003	0.063**	0.062	0.137	0.065*	0.086	0.186	
		(0.030)	(0.055)	(0.125)	(0.033)	(0.059)	(0.125)	
	CCA/EPERxY2004	0.029	-0.002	-0.004	0.032	0.028	0.056	
		(0.034)	(0.060)	(0.132)	(0.036)	(0.057)	(0.117)	

Notes: Dependent variables are first-differenced from 1997 until 2000 and differenced at various intervals thereafter. Column 1 displays OLS coefficient, column 2 displays OLS coefficient on the instrumental variable in the reduced form, and column 3 displays the 2-stage least squares estimate. Columns 4 to 6 have the same setup while including a firm fixed effect. Column 7 reports the number of observations. All regressions include age, age squared, year dummies and region-by-year dummies. Columns 1 to 3 in addition include region and 3-digit industry dummies.

Table 11: Regression in a balanced sample - ARD

DepVar	ExpVar	(1) OLS	(2) Reduced Form (OLS)	(3) IV	(4) Fixed Effects	(5) Reduced Form (FE)	(6) Fixed Effects IV	(7) Obs./ Plants
Energy exp. over gross output	CCA/EPERxY2001	0.044**	0.118***	0.054**	0.341***	0.115**	0.239**	7,101
Δln(EE/GO)		(0.019)	(0.036)	(0.025)	(0.105)	(0.055)	(0.116)	1,545
	CCA/EPERxY2002	0.039*	0.134***	0.052*	0.367***	0.135**	0.280**	
		(0.021)	(0.041)	(0.027)	(0.118)	(0.060)	(0.128)	
	CCA/EPERxY2003	0.036	0.099**	0.051*	0.299**	0.113*	0.236*	
		(0.023)	(0.044)	(0.029)	(0.122)	(0.063)	(0.133)	
	CCA/EPERxY2004	0.053**	0.109**	0.068**	0.319**	0.106	0.220	
		(0.025)	(0.052)	(0.030)	(0.133)	(0.066)	(0.138)	
Energy exp. over variable costs	CCA/EPERxY2001	0.037*	0.124***	0.380***	0.040	0.146***	0.305***	7,101
Δln(EE/VCOST)		(0.019)	(0.036)	(0.106)	(0.025)	(0.051)	(0.113)	1,545
	CCA/EPERxY2002	0.040*	0.166***	0.456***	0.046*	0.184***	0.382***	
		(0.020)	(0.039)	(0.115)	(0.026)	(0.053)	(0.118)	
	CCA/EPERxY2003	0.034	0.137***	0.402***	0.043	0.169***	0.352***	
		(0.023)	(0.041)	(0.119)	(0.027)	(0.055)	(0.124)	
	CCA/EPERxY2004	0.065***	0.160***	0.449***	0.072**	0.176***	0.366***	
		(0.024)	(0.048)	(0.127)	(0.029)	(0.058)	(0.127)	
Energy exp.	CCA/EPERxY2001	0.032*	0.091***	0.251***	0.044*	0.072*	0.149*	7,101
Δln(EE)		(0.019)	(0.032)	(0.094)	(0.023)	(0.039)	(0.082)	1,545
	CCA/EPERxY2002	0.031	0.086**	0.236**	0.048*	0.068	0.142	
		(0.020)	(0.036)	(0.100)	(0.025)	(0.042)	(0.088)	
	CCA/EPERxY2003	0.046**	0.042	0.149	0.060**	0.053	0.111	
		(0.022)	(0.038)	(0.102)	(0.026)	(0.043)	(0.088)	
	CCA/EPERxY2004	0.067***	0.081*	0.229**	0.084***	0.069	0.143	
		(0.023)	(0.046)	(0.116)	(0.028)	(0.049)	(0.099)	
Employment	CCA/EPERxY2001	-0.012	0.019	0.036	0.005	0.028	0.058	7,101
Δln(L)		(0.012)	(0.020)	(0.058)	(0.016)	(0.048)	(0.099)	1,545
	CCA/EPERxY2002	-0.013	0.003	0.003	0.006	0.015	0.031	
		(0.015)	(0.024)	(0.067)	(0.018)	(0.049)	(0.102)	
	CCA/EPERxY2003	0.009	-0.020	-0.044	0.024	0.010	0.021	
		(0.017)	(0.029)	(0.078)	(0.021)	(0.052)	(0.107)	
	CCA/EPERxY2004	-0.006	-0.018	-0.040	0.014	0.006	0.012	
		(0.021)	(0.036)	(0.090)	(0.025)	(0.057)	(0.119)	
Real gross output	CCA/EPERxY2001	-0.011	-0.027	-0.890	-0.010	-0.043	-0.090	7,101
Δln(Real GO)		(0.013)	(0.024)	(0.070)	(0.016)	(0.045)	(0.095)	1,545
	CCA/EPERxY2002	-0.007	-0.048	-0.130	-0.003	-0.067	-0.138	
		(0.016)	(0.034)	(0.084)	(0.020)	(0.055)	(0.116)	
	CCA/EPERxY2003	0.010	-0.056	-0.149	0.009	-0.060	-0.125	
		(0.019)	(0.034)	(0.093)	(0.022)	(0.057)	(0.120)	
	CCA/EPERxY2004	0.014	-0.028	-0.089	0.016	-0.037	-0.077	
		(0.022)	(0.044)	(0.111)	(0.025)	(0.065)	(0.136)	
Total Factor Productivity	CCA/EPERxY2001	-0.006	-0.013	-0.023	-0.014	-0.000	0.001	7,101
Δln(GO)		(0.007)	(0.014)	(0.042)	(0.011)	(0.033)	(0.068)	1,545
	CCA/EPERxY2002	-0.001	0.002	0.007	-0.009	0.007	0.015	
		(0.009)	(0.023)	(0.061)	(0.013)	(0.043)	(0.089)	
	CCA/EPERxY2003	-0.003	0.006	0.015	-0.010	0.013	0.029	
		(0.010)	(0.024)	(0.064)	(0.015)	(0.045)	(0.092)	
	CCA/EPERxY2004	0.010	0.028	0.060	0.003	0.035	0.073	
		(0.011)	(0.028)	(0.073)	(0.015)	(0.049)	(0.101)	
	Δln(M)	0.518***	0.519***	0.519***	0.507***	0.508***	0.508***	
		(0.022)	(0.022)	(0.022)	(0.023)	(0.023)	(0.023)	
	Δln(EE)	0.037***	0.037***	0.036***	0.027***	0.027***	0.026***	
		(0.009)	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)	
	Δln(L)	0.250***	0.250***	0.251***	0.218***	0.218***	0.218***	
		(0.025)	(0.025)	(0.025)	(0.031)	(0.031)	(0.031)	
	Δln(K)	0.082***	0.082***	0.079***	0.108***	0.109***	0.104***	
		(0.019)	(0.019)	(0.019)	(0.026)	(0.026)	(0.027)	

Notes: Dependent variables are first-differenced from 1997 until 2000 and differenced at various intervals thereafter. Column 1 displays OLS coefficient, column 2 displays OLS coefficient on the instrumental variable in the reduced form, and column 3 displays the 2-stage least squares estimate. Columns 4 to 6 have the same setup while including a firm fixed effect. Column 7 reports the number of observations. All regressions include age, age squared, year dummies and region-by-year dummies. Columns 1 to 3 in addition include region and 3-digit industry dummies.

Table 12: Regression in a balanced sample - QFI

DepVar	ExpVar	(1) OLS	(2) Reduced Form (OLS)	(3) IV	(4) Fixed Effects	(5) Reduced Form (FE)	(6) Fixed Effects IV	(7) Obs./ Plants
Total kWh	CCA/EPERxY2001	0.090***	-0.044	-0.095	0.112**	-0.093	-0.252	1,621
Δln(kWh)		(0.030)	(0.060)	(0.179)	(0.048)	(0.110)	(0.281)	452
	CCA/EPERxY2002	0.095**	0.018	0.062	0.122**	-0.065	-0.175	
		(0.043)	(0.101)	(0.272)	(0.057)	(0.157)	(0.382)	
	CCA/EPERxY2003	0.108***	0.093	0.265	0.117**	0.029	0.082	
		(0.041)	(0.064)	(0.200)	(0.054)	(0.117)	(0.284)	
	CCA/EPERxY2004	0.063	0.040	0.123	0.068	-0.062	-0.172	
		(0.050)	(0.066)	(0.199)	(0.063)	(0.118)	(0.297)	
Electricity	CCA/EPERxY2001	0.023	0.011	0.128	0.005	0.037	0.071	1,617
Δln(El)		(0.023)	(0.043)	(0.149)	(0.032)	(0.058)	(0.145)	451
	CCA/EPERxY2002	0.058*	0.158**	0.481**	0.029	0.167*	0.406*	
		(0.032)	(0.064)	(0.219)	(0.039)	(0.088)	(0.230)	
	CCA/EPERxY2003	0.041	0.173***	0.555**	0.013	0.172**	0.431*	
		(0.035)	(0.064)	(0.251)	(0.041)	(0.084)	(0.237)	
	CCA/EPERxY2004	0.035	0.153**	0.502**	0.016	0.115	0.279	
		(0.040)	(0.062)	(0.231)	(0.044)	(0.084)	(0.229)	
Gas	CCA/EPERxY2001	0.023	-0.086	-0.170	0.007	-0.259**	-0.638**	1,318
Δln(Gas)		(0.041)	(0.074)	(0.187)	(0.066)	(0.106)	(0.275)	372
	CCA/EPERxY2002	0.115**	0.135	0.445	0.069	-0.055	-0.105	
		(0.057)	(0.096)	(0.293)	(0.076)	(0.136)	(0.343)	
	CCA/EPERxY2003	0.119*	0.103	0.359	0.081	-0.047	-0.055	
		(0.065)	(0.089)	(0.320)	(0.087)	(0.147)	(0.381)	
	CCA/EPERxY2004	0.061	0.007	0.056	-0.002	-0.150	-0.370	
		(0.072)	(0.081)	(0.249)	(0.092)	(0.132)	(0.338)	
Share of gas over kWh	CCA/EPERxY2001	0.007	-0.022	-0.066	0.013	-0.032	-0.086	1,619
		(0.011)	(0.021)	(0.069)	(0.019)	(0.043)	(0.112)	452
Δ(Gas/kWh)	CCA/EPERxY2002	0.029	-0.001	-0.014	0.040	-0.015	-0.040	
		(0.018)	(0.036)	(0.102)	(0.025)	(0.051)	(0.126)	
	CCA/EPERxY2003	0.024	-0.015	-0.050	0.029	-0.006	-0.014	
		(0.016)	(0.033)	(0.105)	(0.022)	(0.051)	(0.127)	
	CCA/EPERxY2004	0.006	-0.015	-0.051	0.004	-0.012	-0.031	
		(0.020)	(0.037)	(0.113)	(0.027)	(0.052)	(0.132)	
Solid fuels	CCA/EPERxY2001	0.005	-0.119	-0.587	0.105	0.007	0.040	521
Δln(So)		(0.139)	(0.210)	(0.753)	(0.180)	(0.372)	(0.910)	157
	CCA/EPERxY2002	-0.187	0.077	-0.179	-0.144	-0.073	-0.125	
		(0.139)	(0.243)	(1.624)	(0.173)	(0.331)	(0.813)	
	CCA/EPERxY2003	-0.093	-0.572	-1.571	-0.164	-0.469	-0.908	
		(0.240)	(0.592)	(1.747)	(0.254)	(0.586)	(1.098)	
	CCA/EPERxY2004	-0.039	-0.061	-0.466	-0.099	-0.252	-0.377	
		(0.227)	(0.528)	(1.650)	(0.207)	(0.545)	(1.035)	
Solid fuels over kWh	CCA/EPERxY2001	0.013**	-0.002	-0.020	0.023**	-0.008	-0.017	1,621
		(0.005)	(0.012)	(0.035)	(0.009)	(0.024)	(0.059)	452
Δ(So/kWh)	CCA/EPERxY2002	-0.008	-0.041	-0.115	0.004	-0.054	-0.135	
		(0.008)	(0.028)	(0.073)	(0.013)	(0.047)	(0.112)	
	CCA/EPERxY2003	0.000	-0.018	-0.062	0.009	-0.035	-0.086	
		(0.006)	(0.013)	(0.046)	(0.010)	(0.028)	(0.066)	
	CCA/EPERxY2004	-0.000	-0.015	-0.053	0.011	-0.028	-0.068	
		(0.007)	(0.014)	(0.048)	(0.011)	(0.028)	(0.069)	
CO2	CCA/EPERxY2001	0.065***	-0.025	-0.025	0.070**	-0.058	-0.162	1,621
Δln(CO2)		(0.024)	(0.051)	(0.148)	(0.035)	(0.076)	(0.192)	452
	CCA/EPERxY2002	0.078**	0.059	0.185	0.080**	0.009	0.012	
		(0.031)	(0.067)	(0.187)	(0.039)	(0.099)	(0.243)	
	CCA/EPERxY2003	0.080**	0.115**	0.344*	0.074*	0.065	0.169	
		(0.035)	(0.058)	(0.188)	(0.042)	(0.089)	(0.222)	
	CCA/EPERxY2004	0.058	0.066	0.215	0.052	-0.019	-0.066	
		(0.039)	(0.053)	(0.161)	(0.044)	(0.086)	(0.216)	

Notes: Dependent variables are first-differenced from 1997 until 2000 and differenced at various intervals thereafter. Column 1 displays OLS coefficient, column 2 displays OLS coefficient on the instrumental variable in the reduced form, and column 3 displays the 2-stage least squares estimate. Columns 4 to 6 have the same setup while including a firm fixed effect. Column 7 reports the number of observations. All regressions include age, age squared, year dummies and region-by-year dummies. Columns 1 to 3 in addition include region and 3-digit industry dummies.

Table 13: Regression in a common support sample

DepVar	ExpVar	(1) OLS	(2) Reduced Form (OLS)	(3) IV	(4) Fixed Effects	(5) Reduced Form (FE)	(6) Fixed Effects IV	(7) Obs./ Plants
Energy exp. over gross output	CCA/EPER	0.031**	0.098***	0.242***	0.022	0.120***	0.224***	12,739
Δln(EE/GO)		(0.014)	(0.030)	(0.075)	(0.020)	(0.043)	(0.081)	3,724
Energy exp. over variable costs	CCA/EPER	0.030**	0.117***	0.290***	0.010	0.138***	0.258***	12,739
Δln(EE/VCOST)		(0.022)	(0.042)	(0.103)	(0.025)	(0.052)	(0.098)	553
Energy exp.	CCA/EPER	0.022*	0.048*	0.119*	0.030*	0.083***	0.154***	12,739
Δln(EE)		(0.013)	(0.025)	(0.063)	(0.018)	(0.030)	(0.056)	3,724
Total kWh	CCA/EPER	0.069**	0.010	0.024	0.073**	0.009	0.017	3,199
Δln(kWh)		(0.028)	(0.050)	(0.118)	(0.036)	(0.072)	(0.135)	554
Electricity	CCA/EPER	0.026	0.059	0.144	0.033	0.098*	0.186*	3,192
Δln(El)		(0.022)	(0.042)	(0.103)	(0.025)	(0.052)	(0.098)	553
Gas	CCA/EPER	0.027	0.030	0.081	0.007	-0.030	-0.059	2,615
Δln(Gas)		(0.041)	(0.053)	(0.140)	(0.049)	(0.084)	(0.162)	464
Share of gas over kWh	CCA/EPER	0.015	0.014	0.034	0.016	0.015	0.028	3,197
Δ(Gas/kWh)		(0.011)	(0.016)	(0.039)	(0.015)	(0.023)	(0.043)	554
Solid fuels	CCA/EPER	-0.125	-0.232	-0.659	-0.119	-0.201	-0.324	1,054
Δln(So)		(0.110)	(0.231)	(0.604)	(0.121)	(0.292)	(0.448)	217
Solid fuels over kWh	CCA/EPER	0.001	-0.020*	-0.050*	0.003	-0.024	-0.046	3,199
Δ(So/kWh)		(0.004)	(0.011)	(0.028)	(0.006)	(0.017)	(0.031)	554
CO2	CCA/EPER	0.050**	0.021	0.052	0.051*	0.029	0.055	3,199
Δln(CO2)		(0.023)	(0.042)	(0.101)	(0.027)	(0.056)	(0.104)	554
Employment	CCA/EPER	-0.014	-0.046**	-0.115**	0.017	-0.034	-0.064	12,739
Δln(L)		(0.011)	(0.023)	(0.056)	(0.014)	(0.040)	(0.074)	3,724
Real gross output	CCA/EPER	-0.009	-0.050**	-0.123**	0.008	-0.037	-0.069	12,739
Δln(Real GO)		(0.011)	(0.023)	(0.057)	(0.014)	(0.038)	(0.071)	3,724
Total Factor	CCA/EPER	-0.003	0.003	0.008	-0.009	0.008	0.014	12,715
Productivity		(0.006)	(0.016)	(0.040)	(0.010)	(0.029)	(0.054)	3,718
Δln(GO)	Δln(M)	0.477***	0.477***	0.477***	0.467***	0.467***	0.466***	
		(0.014)	(0.014)	(0.014)	(0.018)	(0.018)	(0.018)	
	Δln(EE)	0.035***	0.035***	0.035***	0.035***	0.035***	0.035***	
		(0.006)	(0.006)	(0.006)	(0.008)	(0.008)	(0.008)	
	Δln(L)	0.253***	0.253***	0.254***	0.231***	0.231***	0.231***	
		(0.014)	(0.014)	(0.014)	(0.019)	(0.019)	(0.018)	
	Δln(K)	0.044**	0.044**	0.044**	0.059***	0.059***	0.058***	
		(0.017)	(0.017)	(0.017)	(0.021)	(0.021)	(0.021)	

Notes: Dependent variables are first-differenced from 1997 until 2000 and differenced at various intervals thereafter. Column 1 displays OLS coefficient, column 2 displays OLS coefficient on the instrumental variable in the reduced form, and column 3 displays the 2-stage least squares estimate. Columns 4 to 6 have the same setup while including a firm fixed effect. Column 7 reports the number of observations. All regressions include age, age squared, year dummies and region-by-year dummies. Columns 1 to 3 in addition include region and 3-digit industry dummies.

Table 14: Share of CCA type plants in various aggregates based on the ARD or QFI sample

CCA type firms		
(1)	(2)	(3)
share of energy expenditure	**share of electricity**	**share of kWh**
0.59	0.65	0.71

Notes: Columns report the sum of the outcome variable across plants in the sample weighted by the predicted probability of participating in a CCA.