Journal of Environmental Economics and Management 63 (2012) 208–223

Contents lists available at SciVerse ScienceDirect

Journal of
Environmental Economics and Management

journal homepage: www.elsevier.com/locate/jeem

Anatomy of a paradox: Management practices, organizational structure and energy efficiency[☆]

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ARTICLE INFO

Article history:
Received 26 November 2010
Available online 31 August 2011

Keywords:
Climate policy
Energy efficiency
Firm behavior
Management practices
Manufacturing
Microdata
Organizational structure

ABSTRACT

This paper provides new evidence on the relationship between management practices and firm performance. We interviewed managers of 190 randomly selected manufacturing plants in the UK and matched their responses with official business microdata. We find that climate friendly management practices are associated with lower energy intensity and higher productivity. Firms that adopt more such practices also conduct more climate friendly R&D which will sustain future growth in energy efficiency. Our findings are akin to the "energy efficiency paradox" and highlight the linkages between particular management practices and firm-level energy efficiency. We also find a strong empirical link between climate friendly management practices and organizational structure. Firms are more likely to adopt such practices if climate change issues are managed by the environmental or energy manager, and if this manager is close to the CEO. Adoption is less likely when the CEO is in charge of climate change issues.

1. Introduction

The comeback of energy efficiency as a high-priority topic on policy and research agendas can be attributed to two factors. First, scientists have established a causal link between global climate change and the accumulation of manmade emissions of greenhouse gases (GHG) in the atmosphere. Climate change constitutes a serious threat to ecosystems and to the productive base of economies around the globe [1]. Second, the global surge in the demand for energy, fueled by rapid industrial take-off and changing consumption patterns in emerging economies, has led to unprecedented increases in both the level and volatility of energy prices. As a result, investments in energy-saving technologies have become more attractive from a business point-of-view, both as a way of cutting running costs and as a hedging strategy. In addition, many governments have taken to providing incentives for such investments, be it for reasons related to climate-change or with the stated objective of reducing the dependency on energy imports.

[☆] An earlier version of this paper was circulated under the title "Climate Change Policies and Management Practices".

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doi:10.1016/j.jeem.2011.08.003

The success of policies aiming to improve the efficiency and to lower the carbon intensity of energy use depends crucially on the policy maker's ability to predict how the industrial sector responds to different regulatory measures. This is important not only because this sector accounts for almost 40% of GHG emissions worldwide [2], but also because a large part of the research and development (R&D) that is expected to reduce emissions in the long run is carried out and paid for by private firms. Therefore, effective regulation must provide incentives for both short-run measures to improve energy efficiency *and* R&D investments leading to sustained efficiency growth in the future.

Clearly, any such regulation should be based on scientific evidence. Yet, researchers working in this area have struggled to make sense of the empirical oddity that firms seem to systematically reject energy efficiency upgrades in spite of a positive net present value that results when the calculation is based on the "correct", risk-adjusted cost of capital. This phenomenon has been referred to as the "energy efficiency paradox" or the "energy efficiency gap" (e.g. [3–5]). While there is some evidence for the existence of a paradox, the underlying factors are not yet well understood. If the paradox is driven by frictions or market failures that public policy can address, then the dual objectives of climate change mitigation and energy security can be achieved by removing such frictions—possibly at little or no cost. The challenge remains to identify all the relevant barriers to energy efficiency improvements.

This study uses a unique combination of survey data and official microdata to provide new evidence on this issue. Based on interviews with managers of 190 manufacturing firms in the UK we derive measures for the companies' practices in the areas of energy use and climate change. In addition, we gather independent performance data from both official and commercial sources for the firms in our sample. Based on the interview data alone, we document several aspects of firm behavior relevant for the energy efficiency paradox. For example, firms report that they could achieve substantial carbon savings without compromising on their performance. Moreover, firms use payback criteria that imply high internal rates of return, although few seem to discriminate against energy efficiency projects.

Using "hard" data on energy use and economic performance, we show that a summary index of climate friendly management practices is strongly positively associated with the firm's productivity and negatively so with its energy intensity. Moving from the 25th to the 75th percentile in the distribution of this index is associated with a 23.1% decrease in energy intensity, which corresponds to one-third of the standard deviation within sectors. Analogous to the energy efficiency paradox, this suggests that there might be a win–win scenario from improving climate friendly management which could also raise firm-level productivity. We show that these correlations are driven by a number of specific management practices such as the implementation of targets for energy consumption or more lenient payback criteria for energy efficiency investments, as well as by investors demanding more climate friendly practices. In contrast, we find the association between energy efficiency and various climate policy measures to be much weaker. In further analysis, we explore the linkages between organizational structure and management practices. We find that firms in which climate change issues are managed by the environmental or energy manager are more likely to adopt climate friendly management practices. Hierarchy has a non-monotonic effect, in that the closer this manager is to the CEO the more climate friendly practices are adopted, yet this is not true if the CEO is in charge of climate change issues.

Finally, we analyze the relationship between management practices and measures of climate change related innovation obtained from the interviews. Climate friendly R&D is an important outcome measure because it creates the potential to reduce emissions not only of the company conducting it (via process innovation) but also of the companies' customers (via product innovation). We show that several management practices are positively associated with climate friendly innovation. This suggests the possibility that some of the managerial factors that facilitate energy efficiency investments could also promote climate friendly innovation, thus leveraging their beneficial effect.

Our analysis contributes to the literature in several ways. First, it adds to a series of papers studying the "energy efficiency paradox" in the context of firm behavior (e.g. [4–6]).[1] The failure of firms to adopt profitable, energy-saving innovations has been attributed to market failures such as credit constraints, to uncertainty about the future, and to managerial factors such as lack of information, managerial resources or attention for cost-cutting projects outside the scope of the firm's main business, short-run optimizing behavior or the application of different hurdle rates to energy-related projects. Case studies of energy efficiency programs have shown that firm characteristics influence the adoption decision even when – under the neo-classical paradigm – they should not [8–10]. This paper improves our understanding of the barriers to energy efficiency upgrades more generally as it exploits detailed data on managerial and organizational characteristics from a random sample of manufacturing firms. In addition, our analysis provides a deeper insight into the negative association between lean management practices and energy intensity found by Bloom et al. [11], who did not have data on climate friendly management practices.

The paper also addresses the role of organizational structure for the adoption of new technologies or management techniques. In theoretical work by DeCanio et al. [12,13], the speed of adoption depends to a large extent on the internal hierarchy of the firm, irrespective of the human capital and innate ability of the individuals who form it. Using tractable concepts of organizational structure and hierarchy we test this hypothesis in the context of the adoption of climate friendly management practices. What is more, the paper contributes to the empirical literature on environmental regulation and innovation [14–16], which thus far has produced very little evidence about the drivers of climate friendly innovation at the firm level.[2]

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[1] The paradox has also be examined in the context of consumer choices (see [7], for a survey).

[2] A recent exception is a study by Martin and Wagner [17] on the effect of the Climate Change Levy on patent applications by UK firms.

Not least, our study contributes to the further development of data gathering and matching in this area. The principal obstacle to conducting a joint analysis of organizational structure, managerial practices, energy efficiency, productivity and innovative activity at the firm level is the lack of readily available data. Firm-level data on energy use is subject to strict confidentiality rules in most countries that collect them. While data on innovation is sometimes collected as part of specialized surveys, information on organizational structure and management practices are not reported in official statistics, let alone practices that pertain to climate change issues. Asking people about their motivations and behavior is a straightforward method of eliciting this information, but some precautions need to be taken to avoid that respondents give biased responses [18]. Bewley [19,20] advocates the use of loosely structured interviews instead of questionnaires, particularly in areas where the divergence between observed behavior and theoretical predictions suggests that people's objectives are not understood or that the constraints are misrepresented. Research on the energy efficiency paradox as described in the literature fits this description well.[3] We thus adopt the method of "double-blind" telephone interviews developed by Bloom and van Reenen [21], which minimizes known types of survey biases while preserving random sampling of the respondents. This approach reconciles survey techniques and empirical methods based on "revealed-preference" arguments by matching the survey data to "hard" data on firm performance, in our case to the ORBIS database and to confidential microdata maintained by the Office of National Statistics (ONS).

The remainder of the paper is organized as follows. The next section describes the data and the interview design. It also provides an overview of the responses and describes the linking to business performance data. Section 3 analyzes how energy efficiency and TFP correlate with management practices and policy variables measured in the survey. Section 4 investigates the effect of organizational structure on both management practices and firm performance. Section 5 discusses results on climate-change related innovation. Section 6 concludes and outlines the future directions for our work.

2. Data

2.1. Interviews

We conducted structured telephone interviews with 190 managers at UK production facilities belonging to the manufacturing sector between January and March of 2009. The average interview lasted 42 minutes Firms were selected at random from Bureau Van Dijk's ORBIS database which provides annual accounting data for 55 million companies worldwide.[4] We restricted the sampling frame to all UK firms that had more than 250 but less than 5000 employees in 2007. This is meant to minimize the chance that the interviewers had preconceptions of the company's performance which could bias the assessment. Interviews were conducted with the plant manager or other manager with profound knowledge of the production site such as the production manager, chief operating officer, the chief financial officer, and sometimes the environmental manager. Interviewees were emailed a letter of information in advance of the interview which also assured them their answers were going to be treated as confidential.

Out of 765 manufacturing firms we contacted, 132 refused to participate straight away. In the remaining 443 cases interviewers were asked to call back at another time but did not follow up after the target number of interviews had been achieved. Counting only interviews granted and refused explicitly, we obtain a response rate of 59%.[5] While this is relatively high, sample selection bias might arise if interviewed firms differ in systematic ways from firms that declined to be interviewed. We examine this issue in Section A.3 of the online appendix and find no evidence of sample selection based on observable firm characteristics.[6] The 190 interviewed firms represent a wide variety of activities, size, profitability, age, international activity and ownership.[7]

2.2. Production data

A distinctive feature of our research design is the effort to link the interview data with independent performance data, both as a means of validation and to examine actual impacts. ORBIS data allow us to derive measures of productivity and examine how they relate to various management survey variables. We also match the firms in our sample to observations in the Annual Respondents Database (ARD), the most comprehensive and detailed business dataset for the UK. Data access is restricted to approved researchers working on the premises of the ONS. The ARD contains data on energy expenditures that are of particular interest in this context. Combining look-up tables provided by the ONS for the ORBIS and ARD datasets and information on the facilities' postcode we obtain 130 (68.4%) unique matches for the firms we interviewed.

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[3] For instance, Jaffe and Stavins [5] demand that "explanations must advance beyond the tautological assertion that if the observed rate of diffusion is less than the calculated optimal rate, there must be some unobserved adoption costs that would modify our calculations of what is optimal" (p. 805).

[4] An appendix posted to the *Journal of Environmental Economics and Management*'s online repository of supplementary material (http://www2.econ.iastate.edu/jeem/supplement.htm) provides additional information on the interviews and on the matched performance data.

[5] This is comparable to the 54% response rate obtained in Bloom and van Reenen [21].

[6] The online appendix also spells out the generic conditions for a selection mechanism to generate our main empirical result even in the absence of a true relationship in the population.

[7] See Table A.2 in the online appendix for a summary of firm characteristics.

We consider two alternative measures of energy intensity. The first one, energy expenditures divided by gross output, might be affected by differences in price-cost markups across firms because output is measured in value units and we do not observe firm level output prices. Therefore we consider as an alternative energy expenditure divided by variable costs. If firms adjust their markup in response to a change in the factor input mix, the two measures may not always give the same picture. However, the distributional characteristics of both measures are very similar and they are highly correlated.[8] Most of the variation in energy intensity is driven by differences between firms rather than industries. As the analysis below will show, differences in management practices go a long way to explain this variation.

2.3. *Management practices*

The interviews seek to gather information on three main aspects of firm behavior related to climate change. First, we wish to understand the drivers behind a firm's decision to do (or not) something about GHG emissions. Second, we want to learn about specific management practices that might affect emissions and that firms adopt both voluntarily and in response to mandatory climate change policies. This includes technology adoption and innovation. Finally, we want to assess the effectiveness of various policy measures.

We adopt an ordinal scale of 1 to 5 to measure management practices related to climate change. To score each aspect of management, interviewers ask a series of open questions, starting with a fairly general question and then probing for more details in subsequent questions, if necessary. We provide interviewers with exemplary responses for giving a high versus an intermediate and a low score for the relevant dimension. The goal is to benchmark the scoring of firms according to common criteria. For instance, rather than asking the manager for a subjective assessment of the management's awareness of climate change issues, we gauge this by how formal and far-reaching the discussion of climate change topics is among senior managers. The strong correlation of the scores given by the interviewer and those given by a second team member who listened in but scored independently corroborates the high consistency of scores across interviewers (see Section A.4 of the online appendix).

Table 1 provides an overview of managers' responses.[9] In the remainder of this section we explain selected questions of the interview in more detail and highlight patterns in the raw data which speak to the energy efficiency paradox and to the role of policies and management practices in explaining energy use.

Awareness. The interview begins with a question about the management's awareness of climate change issues. For a medium score we expect some evidence of a formal discussion, e.g. that this has been on the agenda of a management meeting. A high score is given only if it is evident that the management has studied the implications of climate change in detail and that the findings have been integrated into the strategic business plan. We also record whether climate change is perceived as a business opportunity, e.g. if the firm sells climate-change related products.

Competitive and other pressures. To assess the relative impact of climate change policies on competition at home and abroad, we inquire about the firm's standing compared to its domestic competitors and whether regulation has induced the firm to consider relocation to unregulated countries. Moreover, we ask whether consumers and investors demand climate friendly management practices. We gauge the intensity of this pressure by inquiring about the type of information requested by these groups (e.g. mere labeling vs. hard data on GHG emissions).

Government policies. Firms covered by the UK Climate Change Agreements (CCA)[10] and/or the EU Emission Trading Scheme (EU ETS) are asked how stringent these policies are and about their behavior on the permit markets. What is more, we ask about participation in voluntary policies offered by the British government such as the Carbon Trust (CT) energy audits[11] and online tools, the Enhanced Capital Allowance (ECA) scheme,[12] and whether these initiatives were perceived as useful. Exposure to these policies is high in our sample. Out of the 190 firms, 33 were in the EU ETS, 73 were in a CCA and 27 participated in both schemes. Regarding voluntary policies, 131 firms received an energy audit from the Carbon Trust and 27 firms took advantage of the ECA. Furthermore, 41 firms used online tools provided by the Carbon Trust, eight received innovation grants from this institution and 10 adopted the Carbon Trust standard.

Monitoring and targets. Several questions pertain to the firm's rigor in monitoring its energy use and GHG emissions. Monitoring can range from a glance at the energy bill to detailed monitoring of both energy use and carbon flows

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[8] Table A.4 in the online appendix presents descriptive statistics for the ARD variables in the sample of matched firms.

[9] Responses ranked on an ordinal scale may not be comparable across questions as in some cases all firms were given scores between 2 and 4 or 1 and 3. In the regression analysis, we therefore use *z*-scores, computed by subtracting from the raw score the average score and dividing by the standard deviation.

[10] The CCA is a voluntary agreement that offers participating firms an 80% discount on their tax liability under the Climate Change Levy if they promise to reduce their energy consumption. See Martin et al. [22] for a plant-level analysis of its causal impacts on energy use and economic performance.

[11] Set up by the UK government in 2001 as an independent company, the Carbon Trust helps businesses to cut carbon emissions, to save energy and to commercialize low carbon technologies. Among the various services it offers to firms and to the public sector are free energy audits. An independent consultant identifies energy-saving opportunities and supports their practical implementation. If capital expenditure is necessary, the consultant calculates the payback period. A facility's carbon footprint can also be calculated.

[12] This scheme was introduced by the UK government in 2001 as part of the Climate Change Programme. It grants firms a 100% first-year capital allowance against taxable profits on investments in equipment that meets energy-saving criteria. The list of criteria for each type of technology is maintained by the Carbon Trust. The Trust maintains a second list with the products and technologies that are eligible for the ECA.

Table 1
Interview summary statistics.

Management variables	(1) Number of firms responding	(2) Mean	(3) Standard deviation	(4) Answered "don't know"	(5) Refused to answer	(6) Total number
1 **Manager's tenure in post** (Y)	189	5.22	5.25	1	0	190
2 **Manager's tenure in company** (Y)	190	12.20	10.10	0	0	190
3 **Awareness of climate change** (S)	188	3.45	1.08	2	0	190
4 **Climate-change related products** (S)	188	1.77	1.20	2	0	190
5 **Stringency of ETS target** (S)	27	2.85	1.32	6	0	33
6 **ETS target** (P)	10	11.50	14.20	22	1	33
7 **Rationality of behavior on ETS market** (S)	21	2.10	1.34	12	0	33
8 **Stringency of CCA target** (S)	68	3.57	1.01	5	0	73
9 **CCA target** (P)	47	13.10	11.80	25	1	73
10 **Competitive pressure due to climate change** (S)	171	2.60	0.95	19	0	190
11 **Competitive relocation due to climate change** (S)	187	1.11	0.42	3	0	190
12 **Customer pressure** (S)	188	2.60	1.25	2	0	190
13 **Investor pressure** (S)	175	2.57	1.40	15	0	190
14 **Energy monitoring** (S)	186	3.49	1.37	4	0	190
15 **Energy consumption targets** (S)	183	2.90	1.40	7	0	190
16 **Energy consumption target** (P)	109	22.20	17.30	22	1	132
17 **GHG monitoring** (S)	183	2.14	1.27	7	0	190
18 **GHG emissions targets** (S)	165	1.56	1.13	25	0	190
19 **GHG emissions target** (P)	25	21.70	24.50	12	0	37
20 **Target enforcement** (S)	185	2.52	1.43	5	0	190
21 **Measures on site** (S)	183	3.04	1.08	7	0	190
22 **Energy reduction achieved through one recent measure** (P)	96	12.80	13.80	94	0	190
23 **GHG emissions reduction through one recent measure** (P)	42	15.50	18.90	148	0	190
24 **Hurdle rate for investments to improve energy efficiency** (S)	1	1		189	0	190
25 **Payback time for investments to improve energy efficiency** (S)	140	2.11	1.08	48	2	190
26 **Barriers to investments in energy efficiency** (S)	149	2.86	0.63	41	0	190
27 **Research and development—broad innovation** (S)	183	3.25	1.19	5	2	190
28 **Process innovation** (S)	181	2.28	1.10	7	2	190
29 **Product innovation** (S)	176	2.06	1.29	11	3	190
30 **Purchasing choices** (S)	178	2.51	1.29	12	0	190
31 **Further reductions achievable at current prices** (P)	138	8.82	8.60	52	0	190
32 **Further reductions technologically achievable** (P)	128	27.70	20.00	62	0	190
33 **Adaptation to climate change** (S)	174	1.32	0.75	16	0	190

Notes: Values are given as a score between 1 and 5 (S), percentages (P), or years (Y).

embodied in the firm's products and intermediate goods. To be given the highest score, a firm needs external verification of those figures. If monitoring is in place, we ask whether management is given specific targets for energy use and for GHG emissions, how stringent they are and what incentives are provided to achieve them.

Roughly two-thirds (125) of the firms in our sample have targets for energy consumption (17 of which are expenditure targets, the others being quantity targets). The percentage reduction in energy consumption to be achieved over the next five years has a mean of 22.2% and a standard deviation of 17.3. For comparison, the average reduction in energy consumption that firms achieved through a single recent measure is 12.8%. Targets on GHG emissions are much less frequent. Only 37 firms have one, and only 11 of them include indirect GHG emissions. Emission reduction targets for the next 5 years average at 21.7% with a standard deviation of 24.5. Both target stringency and monitoring scores are lower than those associated with energy consumption targets.

Further GHG emission reducing measures. At current energy prices, managers estimated that they could cut GHG emissions on average by an additional 8.8% (median 6.5%) "without compromising on the firm's economic performance". This means that a sizable amount of GHG abatement could be achieved at little or no extra cost. By comparison, an average further emissions reduction by 27.7% was considered technologically feasible, although not necessarily at no extra cost. Of the 139 firms that answered this question, only 21 answered that they have exhausted such possibilities. This finding speaks directly to the energy efficiency paradox and provides a sense of the magnitude of the inefficiencies to be captured.

Investment criteria. We also ask the manager about the most effective, recent measure to reduce GHG emissions at the site, how the firm learned about it and what motivated its adoption. Furthermore, we inquire about measures that were considered but eventually not adopted, and about the reasons for this decision. We record the hurdle rate or payback time applied to these investments and ask whether this criterion is more, less or equally stringent compared to other cost-cutting investments. The ''barriers to invest in energy efficiency improvements'' score is lower than 3 if the criterion for energy efficiency investments is less stringent compared to other projects, and vice versa. The average firm reports a payback time of 3–5 years for energy efficiency investments, and we cannot reject the hypothesis that the same payback time is applied to other cost-cutting projects (two-thirds of the 149 respondents reported equally stringent payback criteria). Does this mean that firms do not discriminate against energy efficiency projects? The answer depends on the amount of risk associated with the different project types. A 4-year payback for a project with constant annual cash flow over a 15-year lifetime amounts to an internal rate of return (IRR) of 24%. While this might be appropriate to adjust for risk in the companies' core business, it might be too high for a standard energy efficiency upgrade using a known technology (e.g. upgrading a boiler, compressed air system or lighting system) which generates a stream of cost savings at low risk [9]. In contrast, energy efficiency improvements could present higher risks if they are embodied in new equipment with more uncertain energy services, or because of the (perceived) variability of energy prices [23,24]. What is more, for a firm with important capital constraints, the payback criterion simply reflects the cost of borrowing and hence does not differ across projects.[13] It therefore appears difficult to use data on investment criteria in isolation to make inferences about the energy efficiency paradox.[14]

Innovation. We distinguish between three dimensions of R&D. We first ask questions about the importance of R&D in the firm globally. Next, we inquire about climate-change related projects that specifically aim at reducing GHG emissions in the production process. Finally, we discuss innovation of products that would allow a firm's customers to reduce GHG emissions in their use. For each type of innovation, we record its geographical concentration in the firm, the motivation behind it and ask about possible other environmental benefits from this type of R&D. Most of the firms in our sample undertake some form of R&D. The distribution of the ''climate-change related process innovation'' score is right-skewed with the majority of firms scoring below the mean. We find that only a minority of firms engage in ''climate-change related product innovation''. Among those who do, the distribution of this measure is approximately symmetric.

Summary indices. In regard to exploiting the interview data for multivariate analysis, we construct summary indices in order to aggregate the vast amount of information we gathered and to deal with inevitable collinearity in the responses. For each of the overarching themes addressed in the interview a summary index is constructed as an unweighted average of the underlying *z*-scores. An overall index of climate-friendliness is constructed as an unweighted average of all summary indices.[15]

3. Management practices and firm performance

3.1. Concepts

We are interested in two closely related measures of firm performance, namely energy efficiency and productivity. It is plausible that ''good management'' increases both outcomes. It can mitigate managerial slack and discourage wasteful practices, thus raising output for a fixed amount of factor inputs. It might also change production in a way that increases output by more than the necessary increment in factor inputs. ''Good management'' is a rather general term that could be interpreted to embrace both management practices and organizational structure. Since we wish to distinguish between these two aspects, we formulate the working hypothesis that a firm's organizational structure determines its energy efficiency *through* its ability to adopt effective management practices and adequate responses to public policy. That is, the ''structural model'' we have in mind consists of (i) a mapping from organizational structures into management practices and (ii) a mapping from management practices into firm outcomes. This section provides empirical evidence on the latter mapping. The former mapping will be the subject of Section 4 below.

3.2. Management practices and productivity

We consider two alternative measures of productivity, namely labor productivity and total factor productivity (TFP) derived from the ORBIS database. We regress the logarithm of turnover on a management variable and on various control variables for firm age, 3-digit industry, macroshocks and interview ''noise''.[16] The regressions in the first column of Table 2 include the logarithm of employment so that the coefficient on the management variable measures its partial correlation with labor productivity. In the second column, we include employment, materials and capital (all in logarithms) as

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[13] We are grateful to an anonymous referee for this observation.

[14] In Section 3 we explore the relationship between criteria stringency and various outcome measures.

[15] Table A.3 in the online appendix explains the construction of the summary indices in detail. Table A.5 reports descriptive statistics.

[16] Interviewer controls include a full set of interviewer dummies and a dummy indicating whether the interviewer had conducted less than 10 interviews. Respondent controls include controls for a technical background, the respondent's knowledge of the firm and concern about climate change.

Table 2
Productivity and energy intensity regressions.

Dependent variable	(1) **Labor productivity**	(2) **TFP**	(3) **Energy intensity**	(4)	(5) **Energy intensity**	(6)
	ln(turnover)	ln(turnover)	ln(EE/GO)	ln(EE/VCOST)	ln(EE/GO)	ln(EE/VCOST)
Overall index	0.354***	0.119**	−0.461*	−0.446**		
	(0.111)	(0.054)	(0.236)	(0.209)		
Awareness index	0.015	0.047**	−0.153	−0.206*	0.065	−0.028
	(0.044)	(0.022)	(0.127)	(0.122)	(0.119)	(0.123)
Competitive pressure index	−0.052	0.014	−0.136*	−0.156**	−0.052	−0.111
	(0.040)	(0.030)	(0.070)	(0.076)	(0.071)	(0.075)
Other drivers index	0.058	0.001	−0.241**	−0.273***	−0.301**	−0.328***
	(0.043)	(0.023)	(0.110)	(0.102)	(0.116)	(0.102)
Innovation index	0.073	0.002	−0.133	−0.147	−0.138	−0.153
	(0.050)	(0.026)	(0.167)	(0.166)	(0.160)	(0.162)
Energy targets index	0.225***	0.075***	−0.285*	−0.194	−0.572***	−0.419**
	(0.050)	(0.027)	(0.148)	(0.130)	(0.155)	(0.161)
GHG targets index	0.237***	0.045	0.206*	0.252**	0.479**	0.483***
	(0.064)	(0.034)	(0.124)	(0.125)	(0.183)	(0.168)
Carbon Trust audit index	0.110**	0.032	−0.079	−0.089	−0.066	−0.106
	(0.048)	(0.028)	(0.081)	(0.074)	(0.069)	(0.072)
ECA index	0.101	0.051*	−0.235*	−0.199*	0.112	0.137
	(0.064)	(0.031)	(0.126)	(0.120)	(0.189)	(0.189)
ETS index	0.122	0.055	0.205	0.123	0.264*	0.119
	(0.077)	(0.051)	(0.159)	(0.146)	(0.149)	(0.141)
CCA index	0.259***	0.038	0.167	0.235	0.248	0.297
	(0.065)	(0.036)	(0.184)	(0.175)	(0.189)	(0.202)
Barriers to invest in energy efficiency score	−0.099**	−0.075**	0.387***	0.460***		
	(0.047)	(0.029)	(0.085)	(0.093)		
Payback time score	0.002	0.008	−0.036	−0.047		
	(0.053)	(0.029)	(0.083)	(0.083)		
Observations	1387	1106	678	680	658	660
Firms	182	153	128	128	123	123
***R*-squared**	0.865	0.952	0.594	0.642	0.697	0.743

Notes: Results in columns 1 to 4 are based on OLS regressions of the dependent variable on a single summary index or score plus control variables. Results in columns 5 and 6 are based on OLS regressions of energy intensity on all summary indices simultaneously plus control variables (results pertaining to individual scores are given in Table 3). The number of observations and firms as well as the *R*-squared vary for each regression in columns 1–4; the numbers reported pertain to the overall index. All regressions include the log of employment, firm age (linear and quadratic terms), 3-digit sector dummies, year dummies, interviewer noise controls (dummies for interviewer identity and for experience less than 10 interviews), and respondent characteristics (dummy for technical background, scores for knowledge about the firm and for concern about climate change issues). In addition, regressions reported in column 2 also include capital and materials (both in logs) as controls. Robust standard errors clustered at the firm level are given in parenthesis.

* significant at 10%.

** significant at 5%.

*** significant at 1%.

additional controls, which is a straightforward way of estimating the correlation between TFP and the management variable of interest.[17]

We find a strong positive association between firm productivity and the climate friendliness index derived from the interview responses. This correlation is statistically significant for both productivity measures. The coefficient is smaller when controlling for capital and materials (0.119 instead of 0.354), suggesting that climate friendliness is associated with additional investment. The strong correlation we find is in line with previous work showing that firms with better management practices are, on average, more productive [21] and more energy efficient [11].[18]

In addition, the present study sheds light on the question of which management practices are driving this result. For example, we find that climate change awareness is positively correlated with TFP. Hence more productive firms are also more likely to have climate-change related products, to expect positive impacts of climate change or to exhibit more awareness of climate change issues among its management. We also find a strong, positive relationship between productivity and the energy targets index, which measures the monitoring of energy use, the presence and stringency of targets as well as their enforcement. Increasing this index from the 25th to 75th percentile is associated with an 11%

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[17] The number of firms drops from 182 to 153 because some firms did not report data on capital and materials.

[18] Related to this, Shadbegian and Gray [25,26] find a positive correlation between production efficiency and pollution abatement efficiency in the US paper and steel industries, even after controlling for observable factors.

improvement in TFP.[19] This finding is striking, as it supports the view that the simple practice of setting targets for energy use and following up on them can have a discernible effect on a firm's productivity.

The coefficient on the score measuring barriers to invest in energy efficiency projects is negative and statistically significant. This implies that firms applying more lenient payback criteria for investments in energy efficiency than for other projects are more productive on average. Remarkably, there is no statistically significant correlation between productivity and the payback time as such, which might be sensitive to the firm's capital constraints or risk aversion. The positive and significant coefficients on GHG targets, CT audit and CCA indices become insignificant once capital is included in column 2. Given the complementarity between energy and capital, capital might act as a proxy for energy use in these regressions and hence control for possible self-selection of energy-intensive firms into these schemes. We also find that TFP is positively associated with the ECA index at 10% significance. While this result could be interpreted as success, it bears noting that the ECA and other climate policies were not implemented with the primary goal of enhancing firm productivity but to promote energy efficiency, which we examine next.

3.3. Management practices and energy efficiency

As a first approximation to the relationship between management practices, climate change policies and energy efficiency, we regress both measures of energy intensity on a single management variable and additional controls. The results are reported in columns 3 and 4 of Table 2. In line with the results for productivity, we find a robust negative relationship between the index of overall climate friendliness and energy intensity. The coefficient estimate implies that, ceteris paribus, energy intensity falls by 23.1% when increasing overall climate friendliness from the 25th percentile to the 75th percentile of the distribution. This corresponds to one-third of the standard deviation in energy intensity within sectors and highlights the economic significance of this relationship.

Next we examine the relationship between energy intensity and more specific measures of climate friendliness. The indices for competitive pressure and other drivers (consumer and investor pressure) are both negatively associated with energy intensity, the former index at 10% and the latter at 5% significance. This suggests that firms might cope with increasing pressure on both product and capital markets by enhancing their energy efficiency. The coefficient on innovation is negative, too, though not statistically significant. Moreover, firms with higher values on the energy consumption targets index are on average less energy intensive, although this result is statistically significant only at the 10% level. In contrast, the coefficients on the index for GHG emission targets are positive and statistically significant. The indices for the two voluntary climate policies (CT energy audit and ECA) are negatively associated with energy intensity, but only the ECA index is statistically significant at 10%. This finding is consistent with the TFP regression.[20] In contrast, the coefficients on the EU ETS and CCA indices are positive but not statistically significant. As both policies target energy intensive firms in the first place, this might simply reflect a selection effect.

We also find a positive and highly significant association between the barriers to invest in energy efficiency score and energy intensity. This means that, on average, energy intensity is higher in firms that apply more stringent payback criteria to energy efficiency projects than to other projects. Again, the effect of payback times per se is not precisely estimated. These results are in line with those obtained previously in the productivity regressions and suggest that the mechanism linking investment criteria and productivity operates through energy efficiency.

Columns 5 and 6 of Table 2 display the coefficient estimates obtained when regressing energy intensity on all summary indices simultaneously.[21] The main difference to the results in columns 3 and 4 is that the coefficients on the competitive pressure and ECA indices lose significance whereas the results for targets on energy consumption and GHG targets gain statistical significance. Notably, we now find a robust negative relationship between energy intensity and the energy targets index and a positive one for the GHG emission targets index. If interpreted in a causal fashion, the former result would tell us that energy targets decrease energy intensity but the latter gives rise to the startling conclusion that GHG targets *increase* energy intensity. One explanation for this could be that firms must switch to more expensive fuels (e.g. from coal to gas) in order to reduce GHG emissions.[22] Furthermore, the coefficient could be biased if we fail to control for an important determinant of the adoption of GHG targets which is also correlated with energy intensity. It seems most plausible, however, that the issue is one of reverse causality. Even if identical GHG emission targets were randomly

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[19] We calculate this as $\exp(1.39 \cdot 0.075) - 1 = 11\%$, where 1.39 is the interquartile range in the index and 0.075 is the coefficient in column 2 of Table 2.

[20] Causality could run either way to generate this correlation. On the one hand, since the ECA is a government subsidy for investments in energy saving equipment, the policy could be effective at increasing investments in energy efficiency improvements, e.g. by relaxing binding credit constraints for projects that are not central to the running of the firm's business. On the other hand, it is possible that firms that are more conscious about curbing energy consumption are both more energy efficient and more likely to participate in policies pertaining to these goals.

[21] Due to missing observations for the policy indices (ECA, Carbon Trust audit, EU ETS and CCA), the number of firms drops to 93 when running this regression. In order to avoid sample selection bias we substitute a constant for missing values of these four indices and include dummy variables that take a value of 1 whenever a substitution is made. This procedure allows us to keep 123 firms in the sample while using the full sample to identify coefficients with non-missing observations (Results from the small sample are qualitatively very similar and are available from the authors upon request.). Since we lack investment criteria scores for one-third of the matched sample, we include them in a separate regression and report the results in panel D of Table 3.

[22] Recall that the numerator of both intensity measures is energy *expenditures.*

Table 3
Regressions of energy intensity on selected interview scores and indices.

	(1)	(2)	(3)
	Energy intensity		**Firms/obs.**
	ln(EE/GO)	ln(EE/VCOST)	
Panel A: other drivers			
Customer pressure score	−0.208	−0.165	107
	(0.130)	(0.119)	582
Investor pressure score	−0.107	−0.195**	
	(0.102)	(0.092)	
R-squared	0.670	0.720	
Panel B: energy targets			
Energy monitoring score	−0.323**	−0.199	112
	(0.135)	(0.125)	610
Energy targets dummy	−0.233**	−0.171*	
	(0.105)	(0.092)	
Target enforcement score	0.049	0.087	
	(0.106)	(0.088)	
R-squared	0.693	0.746	
Panel C: GHG targets			
GHG monitoring	0.128	0.164*	113
	(0.098)	(0.092)	616
GHG target stringency	0.197**	0.179**	
	(0.084)	(0.081)	
R-squared	0.680	0.729	
Panel D: energy efficiency measures			
Measures on site score	−0.197**	−0.019	80
	(0.089)	(0.083)	440
Payback time	−0.096	−0.173***	
	(0.070)	(0.054)	
Barriers to invest in energy efficiency projects	0.346***	0.492***	
	(0.081)	(0.067)	
R-squared	0.787	0.845	

Notes: Results obtained in OLS regressions of energy intensity on normalized interview scores and all summary indices other than the index based on these interview scores. Additional control variables are the same as in Table 2. Robust standard errors given in parenthesis are clustered at the firm level.

* significant at 10%.

** significant at 5%.

*** significant at 1%.

assigned to some firms and not to others (i.e. in the absence of selection) energy intensive firms are more likely to report that the target is stringent. Hence a firm's energy intensity determines its value for the GHG index (via the stringency score) and not vice versa. This explains why, all else being equal, firms with a higher GHG targets index are more energy intensive on average.

Next we take a closer look at the principal constituents of the indices we found to be significant. Table 3 reports the coefficient estimates from regressing energy intensity on the main scores underlying an index, while controlling for all other indices. Panel A shows the decomposition of the "other drivers" index. While both customer and investor pressure exhibit a negative correlation with energy intensity, the coefficient on the latter is more precisely estimated (the large standard errors hint at a multi-collinearity problem). Panel B shows that the components of the energy targets index which matter for energy intensity are energy monitoring and the presence of a target rather than its enforcement or its stringency.[23] The results in Panel C corroborate our conjecture that the correlation between energy intensity and the GHG index is driven by the stringency score. We find that the firms with the most stringent GHG emission targets are also the most energy intensive ones.[24] The positive coefficient on GHG monitoring is significant at 10% at best. Finally, Panel D shows that the earlier result for the investment criteria stringency variables are robust in the multivariate regression. The barriers to investments in energy efficiency score continues to be positively and significantly associated with energy intensity whereas the scores for payback time and measures taken on site are negatively associated with energy intensity and less significant.

In sum, this section has presented ample evidence that differences in energy efficiency across firms within a given sector are strongly associated with measurable differences in management practices and less so with various climate

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[23] We experimented with including the energy target stringency score in this regression both with the energy targets dummy and without it. In neither case is this variable statistically significant.

[24] A separate dummy for target existence is not statistically significant when included in the regression.

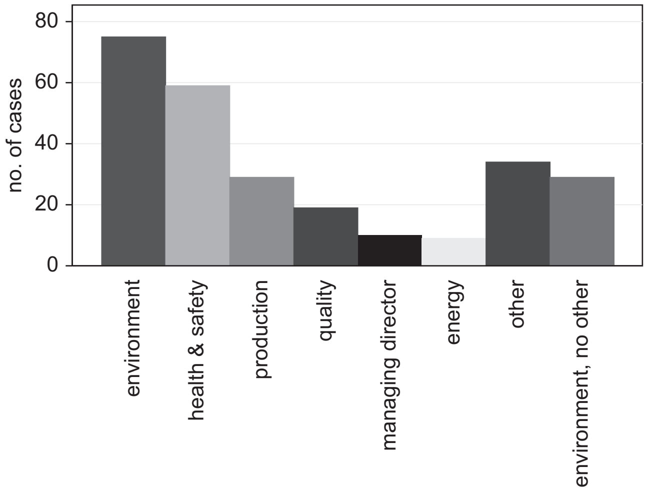

Fig. 1. Main function of manager responsible for climate change issues.

policy measures. With the usual caveats regarding causality, our findings indicate that firms might reduce energy intensity *and* raise overall productivity by adopting certain climate friendly management practices. This win–win scenario is suggestive of the presence of an energy efficiency paradox in that low-cost management practices such as the adoption of targets for energy consumption are likely to pay for themselves through increased productivity. Moreover, a similar relationship found with respect to the stringency of investment criteria could imply that firms are less likely to leave money on the table if they apply more lenient payback criteria to energy efficiency improvements than to other cost-cutting projects. In view of these findings, it seems important to obtain a better understanding of what determines the adoption of certain climate friendly management practices within the firm. This is the goal of the next section.

4. Does organizational structure explain management practices?

4.1. Characterizing organizational structure

Previous research has put forth the idea that organizational structure affects a firm's ability to improve its energy efficiency. For instance, in theoretical models by DeCanio and Watkins [12] and DeCanio et al. [13], the firm is represented as a network of agents and the cost of communication between agents depends on the number of nodes between them. When information about novel ways of enhancing efficiency arrives at one end of the network, this does not translate into better performance until the information has been transmitted to all other agents in the network. Using numerical simulations for different networks, DeCanio et al. show that the optimal organizational structure is subject to a trade-off between connectedness and communication cost.

The subsequent analysis tests a stripped-down version of this idea using a representation of organizational structure which is tractable for regression analysis. Specifically, we use information on the official function(s) of the manager in charge of climate change issues, henceforth referred to as the climate change manager (CCM)[25] as well as information on how far below the CEO this person ranks in the firm's hierarchy. The role of the CCM is likely to affect management practices and performance since different managers have different ways of dealing with climate change issues and regulation. For example, a financial manager is more likely to regard tradable pollution permits as a financial asset whereas a production manager might focus more on complying with the cap implicit in the number of permits allocated to the firm. This is not just because these managers have different professional backgrounds and experiences, but it also reflects the limits of the competences that come with their positions. In our example, the financial manager may lack the authority to instruct the production manager to adjust pollution abatement in response to price fluctuations on the permit market. In turn, the production manager lacks the incentive to do so if permit expenditures and revenues are not part of his profit center. Hence, the closer a CCM is to the CEO, the more possibilities she should have to remedy problems of overlapping competences and ill-defined incentives.

The information we use is derived from responses to the questions "Is anybody responsible for dealing with climate change policies and energy and pollution reduction in the firm?" for which we recorded the manager title and "How far in the hierarchy is this manager below the CEO?" (cf. Fig. A.2 in the online appendix). Out of 178 valid responses, 165 (92%) included the title of the manager in charge. Fig. 1 provides an overview of the different functions these managers have. Roughly 75 managers are specializing in environmental issues, but most of them also occupy other functions, such as

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[25] Note that this need not be the manager interviewed by us.

Table 4
Regressions of management practices on organizational structure.

	(1) **Overall climate friendliness**	(2) **Energy monitoring score**	(3) **Energy targets dummy**	(4) **GHG monitoring score**	(5) **GHG targets dummy**	(6) **Target enforcement score**	(7) **Barriers energy efficiency**	(8) **CCA dummy**	(9) **CT energy audit dummy**	(10) **ECA dummy**	(11) **Product innovation score**
Panel A* : *All firms											
CCM dummy	0.163**	0.776***	0.606**	−0.012	−0.257	0.269	0.145	0.582**	0.292	0.138	−0.247
	(0.078)	(0.289)	(0.251)	(0.235)	(0.240)	(0.173)	(0.230)	(0.235)	(0.304)	(0.263)	(0.234)
Panel B* : *Firms with dedicated climate change manager											
Distance to CEO	−0.093**	0.209**	−0.021	−0.153	−0.139	−0.016	0.370**	−0.094	−0.197	−0.118	−0.217*
	(0.037)	(0.086)	(0.096)	(0.107)	(0.099)	(0.097)	(0.147)	(0.100)	(0.132)	(0.092)	(0.114)
CCM responsibilities environment/energy	0.218***	0.199	0.361*	0.101	0.461***	0.352**	0.184	0.228	0.384**	0.549***	−0.222
	(0.069)	(0.154)	(0.189)	(0.173)	(0.164)	(0.170)	(0.239)	(0.195)	(0.193)	(0.172)	(0.190)
CEO/MD	−0.269**	−0.232	−0.674*	−0.995***	−0.111	−0.299	0.791*	−0.387	−0.999**	−0.163	−0.685**
	(0.132)	(0.396)	(0.386)	(0.381)	(0.229)	(0.317)	(0.426)	(0.321)	(0.435)	(0.368)	(0.299)
Health/safety/quality	0.013	−0.165	0.160	−0.254	−0.125	−0.070	−0.334	−0.268	0.157	0.005	−0.330*
	(0.067)	(0.162)	(0.195)	(0.193)	(0.164)	(0.179)	(0.250)	(0.194)	(0.219)	(0.181)	(0.192)
Production/technical	−0.059	−0.172	−0.068	−0.622***	0.220	−0.145	0.189	−0.325	−0.110	0.351	−0.275
	(0.092)	(0.201)	(0.253)	(0.228)	(0.212)	(0.223)	(0.335)	(0.257)	(0.284)	(0.217)	(0.254)
Observations	130	129	129	128	128	130	107	119	127	115	125
R-squared	0.512	0.476	0.316	0.426	0.364	0.431	0.266	0.444	0.253	0.296	0.457

Notes: OLS regressions of the overall index of climate friendliness (column 1) or normalized interview scores (column 2–10) on the climate change manager's (CCM) hierarchical distance to the CEO and a set of dummy variables for the CCM's main responsibility. Explanatory variables also include firm size and age (linear and quadratic), the share of managers in employment, sector dummies, interviewer noise controls (dummies for interviewer identity and for experience of less than 10 interviews), and respondent characteristics (dummy for technical background, scores for firm knowledge and concern about climate change issues). Robust standard errors in parentheses.

* significant at 10%.

** significant at 5%.

*** significant at 1%.

health and safety, quality manager, etc. From the last column it is evident that not even half of the environmental CCMs are dedicated exclusively to environmental issues. The second question enables us to construct a variable measuring the distance between the CCM and the CEO in terms of management levels. The variable takes a value of 0 if the CCM reports directly to the CEO, a value of 1 if there is a single hierarchy level between the CCM and the CEO, a value of 2 if two hierarchy levels separate them, and so on. The variable ranges between 0 and 5, and its mean and standard deviation are 1.1 and 0.9, respectively. The median and mode are equal to 1, i.e. in most firms of our sample there is a single management level separating the CCM from the CEO.

For further analysis we code dummy variables for the CCM title using the following four categories: (i) environment and energy, (ii) CEO or managing director, (iii) health, safety, and quality, and (iv) operations, production, and technical managers. Other functions are part of the omitted category. We also code a CCM dummy that equals 1 if a firm has a dedicated CCM and 0 otherwise.

4.2. Results

Table 4 reports the results from two sets of regressions. The results in Panel A are based on regressions of management practices on the CCM dummy and control variables. This tells us whether having a dedicated CCM affects management practices. The results in Panel B speak to the effect of organizational structure on management practices. The results were obtained by regressing different management variables on the distance to CEO variable and on the dummies for CCM categories, conditional on the firm having a dedicated CCM. All regressions include controls for the overall size of management, firm and respondent characteristics, and for interviewer noise.

Panel A shows that firms with a dedicated CCM have significantly more climate friendly management practices than those without such a manager. This result arises clearly for the overall index of climate-friendliness as well as for several practices and policies. In particular, we find that firms with a CCM are more likely to participate in a CCA and to adopt energy targets. They also do a better job at monitoring their energy usage than firms without a CCM. Conversely, there is no significant association of the CCM with GHG targets and GHG monitoring, with other voluntary schemes or with the innovation variables.

The estimates in Panel B exhibit three systematic patterns of correlation which are summarized in the coefficient estimates obtained for the overall index of climate friendliness in the first column. First, with respect to the qualitative aspect of organizational structure we find that firms whose CCM is an environment or energy manager have significantly more climate friendly practices ceteris paribus. Second, firms whose CCM is closer in the hierarchy to the CEO are also more climate friendly according to our index. Third, the relationship with hierarchy is non-monotonic. As implied by the negative coefficients on distance and on the CEO/MD dummy, climate friendly practices improve as the CCM moves up in the hierarchy, yet practices become worse again if the CEO himself/herself assumes the responsibilities of the CCM.

In order to identify the practices driving these results, we estimate the same equation for the individual scores underlying the index. We find that having an environmental or energy manager in charge of climate change issues is positively associated with the presence of targets for both energy consumption and GHG emissions.[26] Target enforcement is also significantly higher in firms whose CCM is an environment/energy manager. Furthermore, these firms are more likely to adopt voluntary climate policies such as the Carbon Trust energy audit and the ECA. The patterns of correlation between management practices and the dummy variables for the other functional CCM categories are less significant. The production/technical category of CCM enters the regression on GHG monitoring with a negative sign whereas the coefficient on the health/safety/quality dummy is significant at 10% in the regression of the CCR product innovation score, also with a negative sign. Overall, the qualitative effect of organizational structure seems to be driven mainly by target setting and by the adoption of voluntary climate policies, both of which work better in firms whose CCM is an environmental/energy manager.

The interpretation of the coefficient on the dummy for CEO/Managing Director is slightly different from that of the other CCM dummies in that it compounds the qualitative and the hierarchy aspects.[27] Remarkably, this dummy enters all regressions consistently in the direction of lower climate friendliness. The coefficient estimate is statistically significant in the regressions of the GHG monitoring score, the Carbon Trust energy audit dummy and the CCR product innovation score. It is also significant at 10% for the energy targets dummy, the barriers to energy efficiency investments score and for the CCR process innovation score.

The distance to CEO variable is positively associated with the energy monitoring score and with the barriers to invest in energy efficiency improvements. It is negatively associated with the CCR process and product innovation scores at 10% significance. These results are consistent with the view that the CCM's place in the firm hierarchy determines the climate friendliness of management practices by constraining the range of practices that can be adopted. If interpreted in a causal fashion, our results suggest that a CCM who is at the lower end of the management hierarchy improves the firm's climate friendliness by implementing energy monitoring, i.e. at the *operational* level. In contrast, being high up in the hierarchy

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[26] In the latter case there is also a positive association with the stringency of targets. This and other additional results are reported in Table A.6 in the online appendix.

[27] By definition this manager's place in the firm hierarchy cannot vary across firms.

enables the CCM to improve the firm's climate friendliness by stipulating more favorable investment criteria for energy efficiency projects or by promoting innovation in climate-change related products, i.e. at a more *strategic* level.

As was the case for the overall climate friendliness index, we find that the positive association of climate friendliness and hierarchical proximity between CCM and CEO is reversed when the CEO herself/himself is in charge of climate change issues. Although not always statistically significant, we find this non-monotonic relationship in all regressions except the one for energy monitoring. There are two interpretations of this result. On the one hand, the benefits of being on top of the hierarchy are more than offset by the detrimental effects of multi-tasking, as high opportunity costs prevent the CEO from dedicating more time to climate change management. It follows that this aspect of management could be improved by appointing a dedicated CCM at a level of management just below the CEO. On the other hand, causality could run the other way in that firms giving low priority to climate change issues per se might assign this area as a "residual" responsibility to the CEO.

5. Climate policy, management practices and innovation

The prevention of dangerous levels of global climate change requires substantial abatement of GHG emissions to take place over the next few decades [1]. As far as industrial emissions are concerned, moving firms to the efficiency frontier can provide only a limited amount of abatement unless innovating firms keep on pushing that frontier. If current climate policies in the UK are mainly geared at fostering innovation, one would expect them to stimulate firm-level innovation rather than to improve energy efficiency in the short run. We investigate this by regressing the innovation scores on management practices and policy variables.[28] Table 5 displays the coefficient estimates for these variables obtained in linear regressions where the different dependent variables are the score for CCR process innovation, the score for CCR product innovation, and the score for the importance of general R&D in the company. Each specification is estimated both with and without capital stock in addition to the usual controls.

Regarding the drivers of climate friendly management, we find that each type of CCR innovation is strongly correlated with both the degree of climate change awareness and the importance of CCR products for the firm. This reveals that managers reporting a high awareness of climate change also take real actions of strategic importance related to climate change. The lack of a significant correlation between the competitive pressures index and innovation is in line with our finding that few firms expected strong effects of climate policy on competition and relocation in the first place. In contrast, there is a strong positive correlation between "other drivers" and all types of R&D. Since this index is an average of the scores for investor and customer pressures, we also report the results from separate regressions for the two individual scores. It seems that both factors have an effect of equivalent size. Moreover, the relationship is stronger for CCR process innovation than for CCR product innovation.

Looking at specific measures, we find a strong positive correlation between CCR process innovation with both energy quantity targets and GHG targets. This is an intriguing finding and calls for a closer examination of the underlying mechanisms in future research.[29] Given that energy targets are also associated with higher energy efficiency, it appears that only those firms that have already picked the "low-hanging fruit" need to conduct proper R&D to further improve energy efficiency. The positive association of CCR product innovation is much stronger for GHG targets than for energy targets. Although CCR products primarily help the firm's customers to reduce emissions and not the firm itself, GHG targets contribute to a "climate friendly" image of the firm and hence might play an important role in marketing such products.[30]

In contrast to the results for energy intensity, there is no statistically significant correlation between the score measuring barriers to invest in energy efficiency projects and any of the innovation scores. Hence, we cannot reject the hypothesis that simple payback criteria are inconsequential for the invention and commercialization of new products or processes. This is plausible because R&D spending is a long-term, often strategic investment with uncertain returns for which simple rules-of-thumb hardly seem appropriate.

The coefficients on most of the policy variables are not statistically significant.[31] The lack of significance could mean that climate policies had little impact on innovation, but it could also be owed to the relatively small sample size or to omitted variable bias. Finally, the lack of a significant correlation between innovation and participation in voluntary schemes such as the energy audit by the Carbon Trust and the ECA is consistent with the purpose of these policies, which is to identify suitable options to improve a firm's energy efficiency from a catalog of known technologies and to subsidize their adoption.

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[28] We regress the number of patents held in 2005 (obtained from the European Patent Office) on the overall R&D score and find a robust positive correlation even after controlling for sector, capital stock, size, and interview noise. This gives us confidence that the R&D score is informative about the firm's innovative output. The regression results are available from the authors upon request.

[29] For example, it is possible that senior management embarks on a CCR R&D project and then sets tight energy quantity targets to strengthen the incentives for a successful outcome of the R&D project. Conversely, it could also be that stringent targets are implemented first, and that their presence induces the type of innovation that would be captured by the process innovation score.

[30] According to this idea, the directions of causation for process and product innovation are diametrically opposed in that stringent energy and GHG targets both cause *process* innovation, yet *product* innovation causes GHG targets.

[31] Only the EU ETS index is positively associated with general R&D at the 10% significance level. Adding more covariates to reduce the scope for omitted variable bias causes this relationship to vanish (see Table A.7 in the online appendix). A negative association of CCR product innovation with the CCA index arises which is significant at the 10% level. This is consistent with the negative and significant effect of the CCA on patent applications found by Martin and Wagner [17] and suggests that the mechanism behind this effect is a reduction of CCR product innovation by CCA firms.

Table 5
Regressions of innovation scores on other management variables.

Dependent variable	(1) **CCR process innovation**	(2)	(3) **CCR product innovation**	(4)	(5) **General R&D**	(6)
Awareness	0.343**	0.296**	0.497***	0.497***	0.218	0.244
	(0.134)	(0.139)	(0.140)	(0.137)	(0.142)	(0.150)
CCR products‡	0.422***	0.390**	0.825***	0.760***	0.097	0.107
	(0.146)	(0.154)	(0.160)	(0.183)	(0.179)	(0.198)
Competitive pressures	0.079	0.094	−0.088	−0.130	0.138	0.149
	(0.0705)	(0.0691)	(0.152)	(0.157)	(0.128)	(0.138)
Other drivers	0.429***	0.406***	0.342**	0.298*	0.371***	0.383***
	(0.101)	(0.110)	(0.132)	(0.151)	(0.118)	(0.134)
Customer pressure‡	0.427***	0.355**	0.343*	0.278	0.392**	0.468**
	(0.159)	(0.175)	(0.185)	(0.203)	(0.188)	(0.206)
Investor pressure‡	0.464***	0.495***	0.408*	0.351	0.455**	0.431**
	(0.172)	(0.175)	(0.212)	(0.251)	(0.180)	(0.207)
Energy targets	0.387***	0.393***	0.041	0.109	0.291**	0.297**
	(0.102)	(0.113)	(0.137)	(0.165)	(0.119)	(0.136)
GHG targets	0.495***	0.434***	0.395**	0.364*	0.443***	0.429***
	(0.143)	(0.155)	(0.178)	(0.197)	(0.139)	(0.156)
Barriers to invest in energy efficiency‡	−0.111	−0.151	0.221	0.349	−0.031	0.235
	(0.435)	(0.468)	(0.397)	(0.471)	(0.409)	(0.428)
CCA stringency	0.173	0.119	−0.124	−0.150	0.001	0.022
	(0.121)	(0.137)	(0.138)	(0.153)	(0.124)	(0.150)
EU ETS	−0.043	−0.097	−0.050	−0.019	0.287*	0.424*
	(0.180)	(0.217)	(0.157)	(0.191)	(0.170)	(0.236)
CT energy audit	0.132	0.059	0.075	0.047	−0.076	−0.050
	(0.101)	(0.103)	(0.112)	(0.116)	(0.107)	(0.106)
ECA	0.093	0.136	0.144	0.122	0.165*	0.166
	(0.117)	(0.122)	(0.158)	(0.175)	(0.0925)	(0.104)
Controls for capital stock	No	Yes	No	Yes	No	Yes
Observations	181	163	176	157	183	164

Notes: Results are based on OLS regressions of normalized innovation scores on a single summary index or score (‡, normalized and in logs) plus other controls. All regressions include interviewer fixed effects and sector dummies. Indented variable names indicate that the variable is used in the calculation of the summary index preceding it. Robust standard errors are in parenthesis.

* significant at 10%.

** significant at 5%.

*** significant at 1%.

To sum up, this section has presented evidence that a number of climate friendly management practices are positively associated with climate friendly innovation. An important policy implication of this result is that some of the managerial factors that facilitate energy efficiency improvements could also promote clean innovation, thus leveraging their beneficial effect in the long run. In the short run, the productivity gains associated with the adoption of climate friendly management could partly offset the cost of R&D. The empirical link between existing climate policies and innovation is weaker, which suggests that the design of these policies could be improved to align them with long-term mitigation objectives.

6. Conclusion

There is little doubt that policies aimed at reducing GHG emissions from the industrial sector must strengthen the incentives for improving energy efficiency. Firms can improve energy efficiency by adopting existing technologies or by inventing new technologies that are more energy efficient. The aim of this paper has been to shed new light on how a firm's management practices interact with both these channels, and to pin down specific organizational and managerial constraints that add to the technical difficulties associated with improving energy efficiency. To this end, we interviewed managers at 190 UK manufacturing plants about their management practices and matched their responses to production and energy data from official and commercial sources.

We find that climate friendly management practices are strongly associated with higher productivity and better energy efficiency at the establishment level. This suggests that there might be a win–win scenario from improving environmental management which could also raise firm productivity. This result is suggestive of an "energy efficiency paradox"—the observation that firms fail to adopt energy saving measures despite positive net returns. From a climate policy perspective, an important finding is that climate friendly management is also positively associated with the firm's innovation of cleaner processes and products which are crucial for reducing GHG emissions in the future. Moreover, we have shown that differences in organizational structure can account for a good deal of the variation in management practices across firms. In particular, firms have more climate friendly management practices ceteris paribus if climate change issues are managed by the environmental or energy manager. In addition, hierarchical proximity of the climate change manager to the CEO is associated with more climate friendly management, but the relationship is reversed when the CEO himself is in charge of climate change issues. This suggests that there is a trade-off between the CEO's ability to manage these issues at the most strategic level vs. a higher opportunity cost of time dedicated to them. While causal inference is beyond the scope of this study, we cautiously interpret our findings as evidence that management practices and organizational structure of a firm are crucial for its ability to use energy more efficiently both today and in the future, and to respond to public policy in this area.

Future research on this topic is likely to take three directions. First, the focus on a single country limits the variation in policy variables one can hope for. The limiting factor in expanding this work to other countries (besides researchers' resource constraints) must be seen in the availability of independent performance data, particularly on energy usage. Second, the empirical results of this paper will hopefully inspire research on more accurate models of energy use at the firm level that have testable implications. Finally, future research may be able to exploit exogenous variation that allows for causal inference in testing such models.

Acknowledgments

The authors would like to thank Nick Bloom, Nils-Axel Braathen, Sam Fankhauser, Christos Genakos, Wayne Gray, Rebecca Henderson, Renata Lemos, John Lewellyn, Richard Perkins, Misato Sato, and Peter Young for comments and suggestions. The paper has benefited greatly from the constructive comments of two anonymous referees and the co-editor. The authors are responsible for any errors. Ralf Martin gratefully acknowledges support from the Anglo German Foundation. Ulrich Wagner gratefully acknowledges financial support from the Spanish Ministry for Science and Innovation under Grant SEJ2007-62908.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.jeem.2011.08.003.

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