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Top management and the adoption of energy efficiency practices: Evidence from small and medium-sized manufacturing firms in the US

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ABSTRACT

Barriers to energy efficiency have been extensively discussed in the energy literature, but little is known about positive drivers. This paper investigates the role of top managers and more specifically of top operations managers on the adoption of energy-efficiency practices, based on 5779 energy efficiency recommendations made to 752 small and medium-sized manufacturing firms under the US Department of Energy's IACs (Industrial Assessment Centers) Program, through which teams of students and faculty from engineering schools provide free energy assessments. Top operations managers possess knowledge of production processes, for maximizing the effective manufacture and distribution of goods. We find that their involvement significantly increases the adoption of energy-efficiency initiatives, while involvement of general top managers without an operational role has little or no effect. Involvement of top operations managers increases the percentage of recommended energy savings that are implemented by 13.4% on average and increases the probability of adoption of more disruptive individual recommendations related to process and equipment change from 31% to 44%. Our findings imply that, in order to advance energy efficiency in SMEs (Small and Medium Enterprises), it may be advisable to target managers who are sufficiently senior but still in a clearly operationally-focused position.

1. Introduction

Global atmospheric concentrations of GHG (greenhouse gases) have significantly increased from the pre-industrial values of 280 ppm [1], exceeding 400 ppm during part of 2013. One key strategy proposed by the IPCC (Intergovernmental Panel on Climate Change) to combat this increase is energy efficiency, which they estimate can reduce industrial CO_2 by over 2.5 Gt of CO_2-e per year in 2030, nearly 4% of overall CO_2 emissions in 2030 [2]. However, scholars have shown that several barriers prevent firms from implementing (apparently) profitable energy savings measures [3–6]. Barriers can be classified [4,7] into those related to economic market failure (such as imperfect information and split incentives), economic non-market failure (such as hidden costs or access to capital), behavioral (such as inertia, credibility and trust, or values) and organizational (such as power or culture). The various economic factors are relatively well-documented; for instance, the negative effect on implementation likelihood of an additional dollar in upfront costs is greater than the positive effect of an additional dollar in annual savings [3,8]. More recently several studies have pointed out the importance of "hidden costs" [5,6,9] and of potential production disruption [6,10–12] as additional barriers. Although behavioral and organizational factors are increasingly mentioned, they are not yet as well-documented. In their survey of foundries and brick and tile makers in India, Nagesha and Balachandra [13] (p. 1978) find that "Most of the entrepreneurs do not appear to have the aptitude, knowledge and dynamism required to tackle technology-related problems such as energy efficiency". On the positive side, Rohdin and Thollander [6] report that a key driving force for adoption of energy-efficiency measures in the non-energy intensive sector in Sweden was the presence of individuals with ambition.

Several programs have been implemented to address some of these barriers in the US [3,14], Italy [4] and Sweden [6,10], which involve outside teams that perform energy audits for small and medium-sized firms to identify profitable energy-efficiency opportunities. More recently, in 2012 the European Union adopted the

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directive 2012/27/EU on energy efficiency which requests member states to develop programs to encourage SMEs to undergo energy audits [11]. One such program in the US, is the Department of Energy's (DOE) Industrial Assessment Centers (IACs) program [3,14] which started in 1976 and has provided cumulative energy savings of 1280 trillion BTU by 2005 [15]. This program encourages improvements in industrial energy efficiency by supporting teams of students and faculty from participating engineering schools to conduct free energy, waste, and productivity assessments for small and medium-sized manufacturing firms. The teams perform a one-day on-site energy audit, after which they submit their analysis and recommendations to the firm. The IAC maintains a database of all assessments and recommendations made (including implementation status) since the 1980s, now totaling approximately 16,000 assessments with 121,000 recommendations [16]. However, underinvestment in energy efficiency persists, as implementation rates for the IAC program are generally around 50% even though the payback of projects is usually less than two years [8,17]. Given the observation that individuals can help or hinder a firm's adoption of energy-efficiency, it is natural to ask whether the position of the lead individual involved within the firm matters. Specifically, does it make a difference whether that individual is a top manager, a top operations manager, or someone else? If yes, does the effect of top management involvement vary with the type of recommendation made? While the lack of top management interest in energy efficiency has been suggested as a probable barrier to adoption [18,19], their exact role remains largely unexplored.

In this paper we examine the role of top (general) managers and top operations managers in the adoption of energy-efficiency recommendations. Top (general) managers have titles such as owner, President, and CEO; top operations managers have titles such as VP of Operations or VP of Manufacturing. Top operations managers possess knowledge of raw materials, production processes, quality control, costs, and other techniques for maximizing the effective manufacture and distribution of goods, according to the definition by the US Department of Labor/Employment and Training Administration (US DOL/ETA) [20]. Their goal is to improve manufacturing productivity and to reduce cost, which should make them more likely to favor energy efficiency initiatives relative to other top managers. While all top managers are ideally positioned to coordinate decisions and access resources, top operations managers additionally possess more relevant knowledge. It is therefore interesting to test whether these different abilities impact the adoption of energy-efficiency recommendations.

In order to measure the role of top management on the adoption of energy-efficiency recommendations, we used data from the IAC program covering 5779 recommendations made to 752 small and medium-sized manufacturing firms, from three IACs at SDSU (San Diego State University), at LMU (Loyola Marymount University) and at the UD (University of Dayton). In addition, we participated in five assessments and in follow-up interviews with three firms audited by the SDSU IAC, from which we observed that adoption of energy-efficiency measures was driven by, among others, the position within the firm of the manager who was the main contact for the IAC assessment process. Finally, one of us participated in the IAC Directors' meeting in July 2013, to discuss this and related research with all IAC directors and the DOE managers overseeing the IAC program.

This paper makes several contributions to the energy efficiency literature. First, we examine whether recommendations are more likely to be implemented when top managers or top operations managers lead the process than when other employees do. The distinction between top managers and other employees has been examined before in other contexts, but not yet quantitatively in the energy-efficiency domain, and to the best of our knowledge no study to date in any context has specifically examined the role of top operations managers. Of the 752 assessments in our sample, 176 had top management involvement, including 41 with top operations management involvement.

Second, we use four measures for the extent to which firms "adopt" the energy efficiency recommendations presented to them. We use the traditional binary variable indicating whether a recommendation was implemented or not. In addition, we look at the value of recommendations implemented relative to those identified, measuring value either in terms of potential savings or investment needed, where a higher ratio indicates that the firm adopted a greater proportion of the opportunities identified. Finally, we also look at the average payback of adopted recommendations, where a higher score indicates that the firm adopted recommendations that (on average) will take longer to recover investments, which suggests a greater willingness to adopt. These multiple measures allow us to explore whether top managers, top operations managers, and other employees appear to use different criteria in evaluating energy saving recommendations. We do not have data on the firms' budgets, cash flows, or internal costs of capital, which prevents us from using additional measures of adoption.

Third, we distinguish between recommendations that are more likely to be disruptive, and those that can be implemented during routine maintenance, to explore whether top managers, top operations managers, and other employees respond differently to these different types of recommendation.

This paper is structured as follows. Section 2 reviews the relevant literature and introduces our hypotheses. Section 3 describes our methods, summarizes our observations from the mini-cases and interviews, and presents our data and statistical analysis. Section 4 presents our results. We conclude in Section 5 with some of the limitations of this study.

2. Literature and hypotheses on the role of top managers in energy efficiency

In this section we first review selected literature on adoption of management programs and on energy efficiency, then formulate our specific hypotheses on the role of top managers and top operations managers in the adoption of energy efficiency practices.

2.1. Literature on energy efficiency and on the role of top managers

The energy-efficiency literature proposes several explanations for the underinvestment in energy efficiency [3–6]. One potential explanation relates to organizational failure which occurs when firms face the "split incentive" problem where the economic benefits of energy conservation do not accrue to the agent trying to conserve energy [21]. Another explanation can be traced to the alleged shortsightedness of management [22–24], which could explain why energy efficient investments require shorter payback periods or higher returns than other investments [22,25,26]. It is also possible that energy conservation may not attract top management interest [18,19]. Additionally, it may be costly to acquire information about energy efficient solutions [27]. The DOE's IAC program aims at reducing the information acquisition costs by providing free energy assessments to small and medium-sized firms. Anderson and Newell [8] find that implementation decisions in the IAC program depend more on initial cost than on annual savings, and Muthulingam et al. [28] find that the sequence in which recommendations are presented also matters. However, a comprehensive explanation of adoption rates remains elusive, and the role of top management and top operations managers' involvement has not yet been explored.

Management research on top executives highlights that their experiences, values, and personalities affect the way they filter and process information [29,30], and consequently impacts decisions such as diversification strategies [31], mergers and acquisitions [32], strategic partnerships [33], and diversification [34]. However, little is known about the impact of top executives on operational decisions such as energy efficiency. One exception is Young et al. [35], who examined the impact of top management characteristics on the adoption of TQM (Total Quality Management) practices, but they do not investigate the impact of top managers functional role on the adoption decisions. To the best of our knowledge, no study has investigated the effect of top executives' functional role on adoption of energy efficiency practices.

Literature reviews of practices such as TQM (Total Quality Management) [36], Six Sigma [36,37], ISO 14001 [38], ERP (Enterprise Resource Planning) systems [39], and MIS (Management Information Systems) [40] find that "top management commitment" is essential for successful adoption. Some management systems standards, including ISO 14001 and ISO 50001, specify that top management must designate a member of their team as their representative in the implementation effort [41]. Despite the operational nature of these practices and this operational advice, it is surprising that no academic study so far has investigated whether involvement of top *operations* managers makes a difference.

2.2. Hypotheses

Our first hypothesis predicts that top management involvement will lead to greater adoption of energy-efficiency recommendations. The underlying theoretical mechanisms are associated with various factors related to centralization: of incentives, information, decision horizon, and resources.

First, centralization helps resolve the split incentives issue, where coordination is necessary [7,27], particularly if decision makers are faced with multiple and potentially conflicting recommendations [42].

Second, centralization facilitates access to information required to assess energy savings. Organizations can be inefficient in transmitting information [43] and middle management can influence top management decisions by concealing important information, and by framing issues in particular ways [44,45]. Energy efficiency information is often difficult to access, as energy is consumed across different areas in a firm while usage information is available at an aggregate level across different sources of energy. A top manager may be better positioned to access this information. Moreover, split incentives and information failure can occur simultaneously when part of an organization does not want to share information about energy efficiency projects it will not benefit from, which emphasizes the role of centralization to reduce both types of failures.

Third, strategic decisions that involve longer time horizons are more likely to be made centrally [46]. As top managers are in charge of the long-term vision [47], they will be more likely to implement initiatives that not only have higher savings but that also improve long-term profitability. This is particularly true in privately-held small and medium-sized enterprises (our sample) where top managers are more closely associated with the long-term success of the company, and more engaged in long term planning [48,49]. These reasons lead to our first hypothesis:

Hypothesis 1. *Involvement of top managers in energy efficiency assessments is associated with a higher adoption of energy efficiency practices than involvement by other employees.*

Our reasoning so far applies even more to recommendations that require process or equipment change, as they often require changes to existing routines, organization of work and investment plans. Implementing such recommendations requires overcoming organizational and institutional barriers [50], among others because they are more likely to be disruptive or entail hidden costs [5,6,9,10,12]. Top managers are ideally positioned to overcome these barriers, because they are more able to reallocate resources, while other employees are more likely to perceive resource constraints as given. Therefore, top managers should be more willing than other employees to adopt recommendations requiring process and equipment changes. If H1 is supported for all types of recommendations, it should also hold for those requiring process and equipment changes. To allow for the possibility that H1 does not hold for all types, we revisit H1 for this subset of recommendations:

Hypothesis 2. *Involvement of top managers in energy efficiency assessments is associated with the adoption of more process and equipment change recommendations than involvement by other employees.*

So far, we have focused on top managers in general. Although they are presumed to have a generalist view, each brings to the job an orientation that usually has developed from experience in some primary functional area [29,30]. The literature identifies three broad functional areas. The first relate to "throughput functions", which work at improving the efficiency of the transformation process, and typically the operations function belongs here. The second pertains to "output functions", which focus on the product or service and emphasize growth and search for new opportunities, such as sales and marketing [29,51]. The third category includes areas not integrally involved with the organization's core activities, such as law and finance [52]. Research has shown that individuals in these functions perceive and solve complex problems differently [51,53]. We identify two main types of top managers. The first is general management, with titles such as owner, President, and CEO; the second is operations management, with titles such as VP of Operations or VP of Manufacturing.

Operations managers possess knowledge of raw materials, production processes, quality control, costs, and other techniques for maximizing the effective manufacture and distribution of goods [20]. Their goal is focused heavily on improving manufacturing productivity and reducing cost [54], while general top managers are also concerned with increasing sales and with managing finance, human resources and other functions. Hence, top operations managers should be more likely to favor energy efficiency initiatives relative to other top managers [22,25–27]. In addition, because top operations managers are more familiar with the manufacturing process than top general managers, they should be better able to reduce the disruption associated with process and equipment change recommendations than other managers.

This leads us to our two hypotheses specifically on top operations managers, which parallel our earlier hypotheses on top managers in general:

Hypothesis 3. *Involvement of top operations managers in energy efficiency assessments is associated with a higher adoption of energy efficiency practices than involvement by other employees.*

Hypothesis 4. *Involvement of top operations managers in energy efficiency assessments is associated with the adoption of more process and equipment change recommendations than involvement by other employees.*

Our hypotheses are summarized in Table 1.

3. Data and methodology

In this section we describe the data from the IAC program, introduce the variables used in our regressions, and then describe the estimation methods used.

Table 1
Hypotheses.

	Top managers	Top operations managers
All recommendations	**H 1**: Involvement of top managers is associated with higher adoption of energy efficiency recommendations	**H 3**: Involvement of top operations managers is associated with higher adoption of energy efficiency recommendations
More disruptive recommendations (requiring process and equipment change)	**H 2**: Involvement of top managers is associated with higher adoption of more disruptive recommendations (requiring process and equipment change)	**H 4**: Involvement of top operations managers is associated with higher adoption of more disruptive recommendations (requiring process and equipment change)

3.1. Data

The energy assessments in the IAC program are conducted by teams of engineering faculty and students from over 50 universities that have participated at various times since 1976. For small and medium-sized firms to be eligible for the free assessments, they must fall within SIC (Standard Industrial Classification) codes 20 through 39, be located within 150 miles of the host campus, have gross annual sales below $100 million and less than 500 employees, have annual energy bills between $100,000 and $2 million and have no professional in-house staff to perform the assessment [55].

The first step after a firm signs up for an energy assessment is to gather data on its current energy usage. Next, the IAC team collects operational data during a plant visit, interviews the plant management and identifies some initial improvement opportunities. Based on the visit and data analysis the IAC team submits a report with recommendations to the firm. The IAC uploads information on the assessments, the recommendations and their adoption status, tracked for up to two years, to the IAC database. Our main analysis is based on 5836 recommendations made in 752 assessments between 1985 and 2012.

We use information on assessments done by the IACs at SDSU, LMU and UD. This includes plant level information such as annual sales, number of employees, annual energy usage, annual energy costs, etc., and recommendation-level data such as initial implementation costs, payback in years, annual energy saving potential, implementation status, etc.

We also obtained from those IACs the job title of the key manager involved from each firm in the assessment process, the “contact person”. To better understand this person’s role we interviewed the three IAC directors and the senior management from the DOE who coordinate the IAC program. The consensus was that the “contact person” recorded for each assessment was the individual who was most closely involved with coordinating the assessment efforts when the IAC team visits the manufacturing site, was the point person with whom the IAC interacted to understand the implementation status of the recommendations undertaken, and often was the person charged with coordinating the implementation efforts within the firm. The “contact person” was not necessarily the first person to be contacted within the firm. Fig. 1 details how the “contact person” interacted with the IACs. To further validate our understanding of the role of the “contact person”, the staff member at the SDSU IAC who was in charge of interactions with the client firms revisited their 40 most recent assessments and confirmed that, to the best of his recollection, the “contact person” they had recorded was indeed the individual most involved with the assessment and implementation efforts. We infer that when a top (operations) manager is listed as the main contact, this strongly suggests that top (operations) management was actively involved in the assessment process. Using the “contact person” to assess the extent of involvement of top (operations) managers is also consistent with other studies that measure top management support [40,56]. This measure is not perfect, but the residual ambiguity makes our findings conservative, as the title of the contact person provides a lower bound on the level of seniority involved. If a CEO is listed as main contact, that person must have been involved, while if a lower-level employee is listed, that does not rule out involvement from more senior management. Our comparison is therefore between *known* top (operations) management involvement and *possible* top (operations) management involvement, which biases our study against finding an effect of top (operations) management.

To ground our statistical analysis in practice, we interacted with several IACs and participating firms in several ways. First, we participated in five assessments conducted by the SDSU IAC during 2008–2009, and in three other follow-up phone calls 8–10 months after audits were done. Second, we contacted several firms audited by the LMU IAC as part of an earlier related project [28]. Third, we interviewed senior personnel from eight other IACs, the IAC program’s Technical Field Manager, and the DOE Advanced Manufacturing Office’s IAC coordinator.

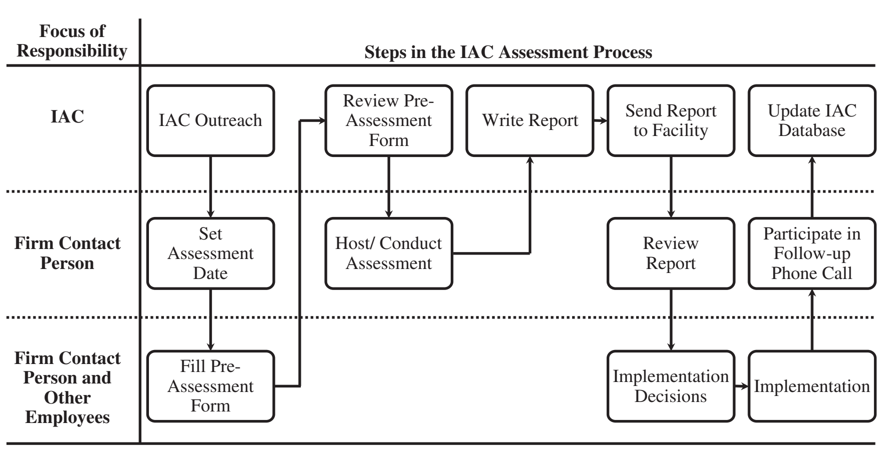

Fig. 1. IAC assessment process indicating the steps where the “contact person” interacted with the IAC program.

We initially performed our analysis with the 1556 recommendations from 203 assessments by SDSU. Afterward, to assess the robustness of our findings, we collected additional data from LMU (836 recommendations in 112 assessments) and UD (3403 recommendations in 437 assessments) and repeated the statistical analysis. We present the complete statistical analyses in Section 4, after introducing the variables and estimation methods. Tables 2 and 3 provide descriptive statistics and correlations. Of the 5836 recommendations, 1214 (from 176 assessments) had top management involvement, including 281 recommendations (41 assessments) with top operations management involvement. We exclude 57 outliers from 50 distinct assessments with payback longer than 7 years. The average assessment has 7.91 recommendations. Of the 5779 recommendations used in our analysis, 2554 recommendations were adopted. The average payback period (implementation cost divided by annual savings) is 0.966 years, the average implementation cost is $24,483 and the average annual saving is $28,769. The average firm had annual sales of $39.38 million, 180 employees, and average plant size of 209,273 square feet.

3.2. Variables

To test our hypotheses, we use OLS (ordinary least-squares) and logit regression models. In each case, the dependent variable is one of our four measures of the extent to which the firm "adopted" the energy efficiency recommendations presented; we introduce those four measures first. Next we introduce the main independent variables: whether top (operations) managers were involved, and whether the recommendation required process or equipment change. Finally, we introduce our control variables for characteristics of the firm, the assessment, the IAC, and other

Table 2
Summary statistics.

Variable	Mean	Std dev	Min	Max	N
Implementation status (1 = Yes)	0.442	0.497	0	1	5779
Payback (in years)	0.966	1.200	0	6.982	5779
Implementation cost (in US$)	24,483	131,059	0	3,037,200	5779
Annual saving (in US$/year)	28,769	128,184	34	5,160,984	5779
Serial position of a recommendation	5.397	3.703	1	21	5779
Process or equipment change	0.408	0.491	0	1	5779
Top management	0.234	0.424	0	1	752
Top operational managers	0.055	0.227	0	1	752
Top general managers	0.180	0.384	0	1	752
Average payback of an assessment	1.001	0.593	0	6.283	752
Total savings identified/firm sales	0.010	0.020	0[a]	0.305	742
Number of recommendations	7.910	3.798	1	21	752
Energy costs (in million US$)	0.657	0.975	0[a]	8.489	752
Sales (in million US$)	39.382	62.006	0[a]	931.500	752
Plant area (in million sq. ft.)	0.209	1.919	0[a]	52.272	752
Employees	180	178	0[a]	1900	752

Note: Statistics are based on 5779 recommendations, representing 752 assessments. (Of these, 2554 recommendations were implemented.)

[a] The data from IAC has value 0 for: 1) Sales (10 Assessments), 2) Employees (1 Assessment) and 3) Energy Costs (45 assessments) and 4) Plant Area (154 Assessments). Our results are valid even if we exclude these data from our analyses.

Table 3
Correlations for select variables used in the analyses (pairwise correlations with * indicating significance at 0.05 levels).

	Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Implementation status (1 = Yes)	1.0000														
2	Payback (in years)	−0.1379*	1.0000													
3	Implementation cost (in US$)	−0.0724*	0.2177*	1.0000												
4	Annual saving (in US$/year)	−0.0491*	−0.0215	0.5700*	1.0000											
5	Serial position of a recommendation	−0.0665*	−0.0201	−0.0629*	−0.0181	1.0000										
6	Process or equipment change	−0.1750*	0.1821*	0.1440*	0.0949*	−0.0307*	1.0000									
7	Top management	0.0355*	−0.0144	−0.0448*	−0.0406*	−0.0667*	−0.0404*	1.0000								
8	Top operational managers	0.0305*	0.0204	0.0027	−0.0137	−0.0294*	0.0074	0.4384*	1.0000							
9	Top general managers	−0.0129	−0.0089	−0.0028	−0.0176	−0.0137	0.0226	−0.3615*	−0.1585*	1.0000						
10	Average payback of an assessment	−0.0567*	0.4228*	0.0749*	−0.0303*	−0.0681*	0.0867*	−0.0314*	0.0476*	−0.0228	1.0000					
11	Total savings identified/firm sales	0.0043	0.0035	−0.0032	−0.0004	−0.0184	0.0317*	−0.0204	−0.0090	−0.0062	0.0511*	1.0000				
12	Number of recommendations	−0.0865*	−0.0514*	0.0395*	0.0435*	0.5645*	−0.0180	−0.1169*	−0.0584*	−0.0243	−0.1220*	−0.0219	1.0000			
13	Energy costs (in million US$)	−0.0321*	−0.0085	0.1484*	0.1728*	0.1664*	0.0488*	−0.1804*	−0.0432*	−0.0263*	−0.0102	0.0192	0.2851*	1.0000		
14	Sales (in million US$)	−0.0258*	−0.0047	0.0424*	0.0593*	0.1199*	0.0106	−0.2005*	−0.0160	−0.0180	−0.0124	−0.0272*	0.2142*	0.3521*	1.0000	
15	Plant area (in sq. ft.)	−0.0198	−0.0014	0.0211	0.0302*	0.0062	0.0391*	−0.0442*	−0.0156	0.0402*	−0.0036	0.0026	0.0117	0.1502*	0.0573*	1.0000
16	Employees	−0.0157	−0.0026	0.0677*	0.0650*	0.1019*	0.0275*	−0.1937*	0.0232	−0.0696*	−0.0029	0.0693*	0.1801*	0.2872*	0.6581*	0.0447*

factors. All variables are summarized in Table 4. After introducing the variables, we formulate our regression models.

3.2.1. Dependent variable: measures of adoption of recommendations

We use four measures of adoption of energy efficiency practices, three at the assessment level and one at the recommendation level.

Proportion of Savings Realized — Our first measure is the proportion of total savings identified in an assessment that corresponds to recommendations that are implemented. Let b_{ij} be the expected annual savings for recommendation i in assessment j and $\mathbf{r}_j$ the subset of M_j recommendations implemented out of the set $\boldsymbol{R}_j$ of all N_j recommendations in assessment j. The proportion of savings adopted $B_{ij} = \sum_{i \in \boldsymbol{r}_j} b_{ij} / \sum_{i \in \boldsymbol{R}_j} b_{ij}$.

Proportion of Costs Invested — Our second measure is the total implementation costs of adopted recommendations as a proportion of total implementation costs across all recommendations in that assessment, $C_{ij} = \sum_{i \in \boldsymbol{r}_j} c_{ij} / \sum_{i \in \boldsymbol{R}_j} c_{ij}$, where c_{ij} is the implementation costs for recommendation i.

Average Payback of Implemented Recommendations — Our third measure is the average payback of recommendations in assessment j that were implemented, $\mathrm{IR}_j = \sum_{i \in \boldsymbol{r}_j} \mathrm{PB}_{ij} / M_j$, where $\mathrm{PB}_{ij} = c_{ij}/b_{ij}$ is the payback (in years) of a recommendation. (Note: we deliberately use the unweighted average payback.)

Adoption of Individual Recommendations — Our final measure $Y_{ij} = 1$ if and only if recommendation i in assessment j was implemented, and 0 otherwise.

3.2.2. Main independent variables

Top Operations Managers and Top General Managers — The four authors independently classified the job title of the contact person as top management, top operations management or neither, using the definition provided by US DOL/ETA [20]. A common method of assessing the reliability of such coding is to use the kappa statistic, defined by Landis and Koch [57] to indicate "the extent to which the observational probability of agreement is in excess of the probability of agreement hypothetically expected under baseline constraints." In our case the kappa statistic is 0.69, which is well within the range of 0.61–0.80 which Landis and Koch [57] consider

Table 4
Variables used in our analyses.

Types of variables	Variable name	Description	Nomenclature used in our analyses
Dependent variables	Proportion of savings realized	Proportion of total savings identified across all recommendations in an assessment that were implemented.	B_{ij}
	Proportion of costs invested	Proportion of total implementation costs across all recommendations in an assessment that were implemented.	C_{ij}
	Average payback of implemented recommendations	Average payback of recommendations in an assessment that were implemented.	IR_j
	Adoption of individual recommendations	Indicator variable which identifies whether a recommendation was implemented or not.	Y_{ij}
Independent variables	Top management	Indicator variable which identifies whether the contact person from the client organization was a top management person or not	$U_j = 1$ if contact person is top manager and 0 otherwise
	Top operations manager	Indicator variable which identifies whether the contact person from the client organization was a top management person with an operational role or not	$U_j = 1$ if contact person is top operations manager and 0 otherwise
	Top general manager	Indicator variable which identifies whether the contact person from the client organization was a top management person with a generalist role or not	$U_j = 1$ if contact person is top general manager and 0 otherwise
	Process and equipment change recommendations	Indicator variable which identifies whether a recommendation requires investment in equipment or involves process changes	This variable is used to identify the sub sample for our analyses of econometric specification (3)
Control variables	Firm's energy costs	Total energy costs (in million US$)	E_j
	Economic characteristics of a recommendations	These include variables to capture the effect of upfront implementation costs and annual savings of a recommendation. All costs are measured in US $.	$\ln(\mathrm{Cost}_{ij})$; $[\ln(\mathrm{Cost}_{ij})]^2$; $\ln(\mathrm{Saving}_{ij})$; and $[\ln(\mathrm{Saving}_{ij})]^2$
	Type of recommendations	Indicator variable to identify a recommendation's technical type.	The indicators are in the matrix T_j
	Serial position of a recommendations	Integer variable indicates the position in which a recommendation appeared in a list of recommendations.	SP_{ij}
	Total number of recommendations in an assessment	Integer variable that indicates the total number of recommendations made.	N_j
	Total savings identified/firm sales	Ratio of savings identified in an assessment to firm sales.	V_j
	IAC control	Indicator variable to identify the IAC that performed the assessment.	The indicators are in the matrix T_j
	Year of assessment	Indicator variables for the year in which the assessment was done.	The indicators are in the matrix T_j
	Industry	Indicator variable to identify the firm's 2 digit SIC code	The indicators are in the matrix T_j
	Firm level controls	Annual sales (in million US$), number of employees (in thousands), and plant area (in million sq. ft.).	S_j represents sales and the other variables are in the matrix T_j

representing substantial agreement. Job titles on which the raters disagreed were discussed again and we used a conservative classification approach, only coding a person as top (operations) management if there was consensus. Overall 176 individuals out of 752 were classified as top management, of which 41 were classified as top operations managers and 135 as top general managers. Table 5 shows the categorization. We do not classify 'Director of Operations' as top (operations) management because the literature provides several examples where Directors are designated as not belonging to top management [58,59].

Process and Equipment Change Recommendations – We classify the recommendation types into those which need investment in equipment or involve process changes and those which can be done as part of regular maintenance. The classification was done independently by a former director of an IAC and one author of this paper, a former operations consultant who has worked for over a decade on projects similar in nature to the IAC assessments. The kappa statistic is 0.88, well above the 0.81 threshold that represents almost perfect agreement [57]. Raters discussed cases where they differed and agreed on the relevant classification. Of the 5779 recommendations, 3447 can be done as part of regular maintenance and the remaining 2332 need either investment in equipment or significant changes in processes.

3.2.3. Control variables

We introduce several control variables to correct for other factors, beyond those addressed in our hypotheses, that influence adoption of energy efficiency recommendations, For instance, recommendations with higher upfront costs or lower annual savings (all else being equal) are less likely to be implemented, regardless of whether top (operations) managers are involved.

Firm's Energy Costs – We use a control E_j which represents the firm's total energy costs.

Economic Characteristics of a Recommendation – We follow Anderson and Newell [8] and control for the implementation costs and annual savings associated with a recommendation by including $\ln(\text{Cost}_{ij})$, $\ln(\text{Cost}_{ij})^2$, $\ln(\text{Saving}_{ij})$ and $\ln(\text{Saving}_{ij})^2$. Similar to Ref. [8] the logarithmic form yields superior fit but the linear form provides similar results.

Type of Recommendation – The IAC classifies recommendations using the 5-digit ARC (Assessment Recommendation Code) [55]. We control for the 25 major types of recommendation using the first two digits of the ARC, as in Anderson and Newell [8].

Serial Position of Recommendation – Muthulingam et al. [28] find that the order in which recommendations appear in the report impacts adoption, so we include serial position SP_{ij} as a control.

Table 5
Top management categorization.

Job description	Frequency (number of assessments)	Top management	Top operations manager	Top general manager	Other
Vice President of Operations	19	X	X		
Vice President of Manufacturing	14	X	X		
Vice President of Engineering	2	X	X		
Chief Operating Officer	1	X	X		
General Manager Manufacturing	1	X	X		
General Manager of Operations	1	X	X		
Senior Vice President of Manufacturing	1	X	X		
Site Executive	1	X	X		
Vice President of Facilities	1	X	X		
President	53	X		X	
Vice President	30	X		X	
General Manager	23	X		X	
CEO	7	X		X	
Chief Financial Officer	4	X		X	
Executive Vice President	4	X		X	
Owner	4	X		X	
President-CEO	3	X		X	
Vice President of Finance	3	X		X	
Vice President/General Manager	2	X		X	
Vice President Distribution & Occupancy	1	X		X	
Vice President Sales & Marketing	1	X		X	
Plant Manager	102				X
Plant Engineer	29				X
Facilities Manager	28				X
Maintenance Manager	27				X
Operations Manager	24				X
Maintenance Supervisor	18				X
Engineering Manager	13				X
Production Manager	13				X
Project Engineer	12				X
Director of Operations	10				X
Manufacturing Manager	10				X
Controller	8				X
Chief Engineer	7				X
Process Engineer	7				X
Electrical Engineer	6				X
Industrial Engineer	6				X
Manufacturing Engineer	6				X
Engineer	5				X
Others (Includes 193 distinct designations which do not appear more than 4 times in our data)	245				X

Total Number of Recommendations in an Assessment – We use this as a control, N_j, because choice can be affected by the number of options provided [60].

Average Payback of an Assessment – To control for the average profitability of the entire assessment, we use the average payback of recommendations $A_j = \sum_{i \in \boldsymbol{R}_j} \mathrm{PB}_{ij}/N_j$.

Total Savings Identified/Firm Sales – To control for the aggregate potential economic relevance of the entire assessment to the firm, we control for total savings identified in an assessment as a proportion of the firm's sales S_j, defined as $V_j = \sum_{i \in \boldsymbol{R}_j} b_{ij}/S_j$.

IAC Control – To control for possible unobservable IAC-related factors, we include a control for the three IACs.

Year of Assessment – We use indicators for the year in which the assessment was done to control for macro-economic factors, including energy costs.

Industry – We control for industrial sector using the firm's two-digit SIC code.

Other Firm Level Controls – Following Anderson and Newell [8] we control for annual sales, number of employees and plant area.

3.3. Estimation methodology

Our analyses involve three comparisons: first, we compare top managers (with and without an operational role) against all other employees; second, we compare top operations managers against all other employees (including top non-operations managers); and finally, we compare top general managers (i.e. top managers without an operational role) against all other employees (excluding top operations managers). These specific comparisons were chosen in order to make our results more conservative, as explained later. All analyses were done using STATA version 10.1.

Hypotheses 1 and 3 predict that involvement of top (operations) managers is associated with higher adoption of energy-efficiency practices. We test this at the assessment and at the recommendation level. The first two measures at the assessment level are the proportion of savings realized (B_j) and the proportion of costs invested (C_j), leading to the following two models, estimated using OLS:

$$B_j = a + U_j{*}\gamma + A_j{*}\varsigma + V_j{*}\psi + E_j{*}\eta + N_j{*}\lambda + S_j{*}\varphi + \boldsymbol{T}_j{*}\omega + \varepsilon_j \tag{1a}$$

$$C_j = a + U_j{*}\gamma + A_j{*}\varsigma + V_j{*}\psi + E_j{*}\eta + N_j{*}\lambda + S_j{*}\varphi + \boldsymbol{T}_j{*}\omega + \varepsilon_j \tag{1b}$$

where U_j is the dummy variable for top management (Hypotheses 1 and 2) or top operations management (Hypotheses 3 and 4); the matrix $\boldsymbol{T}_j$ includes controls for the number of employees, plant area, two digit SIC codes, the specific IAC which did the assessment, and year of assessment; ε_j represents the error terms. The results are shown in Tables 6a and 6bb.

The third measure tests whether top (operations) managers adopt recommendations with longer payback as compared to other employees, using the following OLS model:

$$\mathrm{IR}_j = a + U_j{*}\gamma + V_j{*}\psi + E_j{*}\eta + N_j{*}\lambda + S_j{*}\varphi + \boldsymbol{T}_j{*}\omega + \varepsilon_j \tag{2}$$

where IR_j is the average payback of implemented recommendations, and the rest are as defined in (1). The results are shown in Table 7.

To understand the impact of top (operations) managers' involvement on adoption at the individual recommendation level, we estimate a logit model similar to Anderson and Newell [8]:

Table 6a
Estimation results for OLS model for proportion of savings implemented – Equation (1a).

Dependent variable: proportion of savings implemented			
	(1)	(2)	(3)
Top management	0.053^{+}		
	(0.03)		
Top operations managers		0.134^{*}	
		(0.05)	
Top general managers			0.018
			(0.04)
Average payback of an assessment	-0.080^{***}	-0.084^{***}	-0.078^{***}
	(0.02)	(0.02)	(0.03)
Total saving identified/firm sales	0.000	0.000	0.000
	(0.00)	(0.00)	(0.00)
Total energy costs (in millions)	−0.007	−0.008	−0.008
	(0.01)	(0.01)	(0.02)
Number of recommendations	−0.003	−0.004	−0.004
	(0.00)	(0.00)	(0.00)
Sales (in millions)	0.000	0.000	0.000
	(0.00)	(0.00)	(0.00)
Employees (in thousands)	−0.071	−0.090	−0.087
	(0.08)	(0.08)	(0.08)
Plant area (in million sq. ft.)	0.007^{***}	0.007^{***}	0.007^{***}
	(0.00)	(0.00)	(0.00)
Additional controls			
IAC	Yes	Yes	Yes
SIC	Yes	Yes	Yes
Year	Yes	Yes	Yes
R square	0.25	0.26	0.25
Adjusted R square	0.18	0.19	0.18
Number	742	742	701

Standard errors are in parentheses; $^{+}p < 0.1$, $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.
Note: '$p < 0.1$' indicates that the probability of a false positive finding is less than 10%, under the assumptions of classical statistics. Data pertains to recommendations made by SDSU IAC during 2000–20011. All analyses use robust standard errors. '$p < 0.1$' indicates that the probability of a false positive finding is less than 10%, under the assumptions of classical statistics. 10 of the 752 assessments are excluded from the results reported here, as the sales for these firms were recorded as 0 in the IAC database. Including these 10 assessments in our analyses does not make significant changes to the results or the inferences drawn.

$$Y^{*}_{ij} = a + \mathbf{M}_{ij}{*}\boldsymbol{\beta} + U_j{*}\gamma + A_j{*}\varsigma + V_j{*}\psi + E_j{*}\eta + N_j{*}\lambda + S_j{*}\varphi + \mathrm{SP}_{ij}{*}\chi + \boldsymbol{T}_j{*}\omega + \varepsilon_j \tag{3}$$

where $\mathbf{M}_{ij}$ is the vector of economic variables ($\ln(\mathrm{Cost}_{ij})$, $\ln(\mathrm{Cost}_{ij})^2$, $\ln(\mathrm{Savings}_{ij})$ and $\ln(\mathrm{Savings}_{ij})^2$); and the remaining terms are as defined in (1). The results are shown in models (1), (2) and (3) of Table 8.

Hypotheses 2 and 4 predict that involvement by top (operations) managers is associated with greater adoption of recommendations that involve process or equipment change. To test this we use model (3) but restrict the analyses to recommendations that involve process or equipment change (2332 recommendations out of the 5779). The results are shown in models (4), (5) and (6) of Table 8.

4. Results and discussion

We first discuss our results for top management involvement and then those for top operations management. In Table 6a, for proportion of savings realized, the coefficient of top management in model (1) is positive with a significance level $p < 0.10$ (indicating that the probability of a false positive finding is less than 10%, under the assumptions of classical statistics). For an average assessment in model (1), the presence of top management increases the proportion of savings adopted by 5.3 percentage points. In Table 6b, for proportion of costs invested, the coefficient of top management in

Table 6b
Estimation results for OLS model for proportion of costs implemented – Equation (1b).

Dependent variable: proportion of costs implemented	(1)	(2)	(3)
Top management	0.025		
	(0.03)		
Top operations managers		0.111*	
		(0.06)	
Top general managers			−0.012
			(0.04)
Average payback of an assessment	−0.054*	−0.058*	−0.044*
	(0.02)	(0.02)	(0.03)
Total saving identified/firm sales	0.000	0.000	0.000
	(0.00)	(0.00)	(0.00)
Total energy costs (in millions)	−0.009	−0.009	−0.009
	(0.01)	(0.01)	(0.01)
Number of recommendations	−0.007	−0.007	−0.007+
	(0.00)	(0.00)	(0.00)
Sales (in millions)	0.000	0.000	0.000
	(0.00)	(0.00)	(0.00)
Employees (in thousands)	−0.049	−0.059	−0.084
	(0.09)	(0.09)	(0.10)
Plant area (in million sq. ft.)	0.010***	0.010***	0.010***
	(0.00)	(0.00)	(0.00)
Additional controls			
IAC	Yes	Yes	Yes
SIC	Yes	Yes	Yes
Year	Yes	Yes	Yes
R square	0.25	0.25	0.25
Adjusted *R* square	0.18	0.19	0.18
Number	742	742	701

Standard errors are in parentheses; $^{+}p < 0.1$, $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.
Note: '$p < 0.1$' indicates that the probability of a false positive finding is less than 10%, under the assumptions of classical statistics. Data pertains to recommendations made by SDSU IAC during 2000–20011. All analyses use robust standard errors. '$p < 0.1$' indicates that the probability of a false positive finding is less than 10%, under the assumptions of classical statistics. 10 of the 752 assessments are excluded from the results reported here, as the sales for these firms were recorded as 0 in the IAC database. Including these 10 assessments in our analyses does not make significant changes to the results or the inferences drawn.

Table 7
Estimation results for OLS model for average payback of implemented recommendations.

Dependent variable: average payback of implemented recommendations	(1)	(2)	(3)
Top management	0.076		
	(0.07)		
Top operations managers		0.209+	
		(0.13)	
Top general managers			0.005
			(0.08)
Total saving identified/firm sales	0.000	0.000	0.000
	(0.00)	(0.00)	(0.00)
Total energy costs (in million US$)	0.020	0.018	−0.022
	(0.05)	(0.04)	(0.03)
Number of recommendations	−0.009	−0.009	−0.008
	(0.01)	(0.01)	(0.01)
Sales (in million US$)	−0.001*	−0.001*	−0.001+
	(0.00)	(0.00)	0.00
Employees (in thousands)	0.308	0.281	0.239
	(0.18)	(0.19)	(0.19)
Plant area (in million sq. ft.)	0.025***	0.025***	0.026***
	(0.00)	(0.00)	(0.00)
Additional controls included			
IAC	Yes	Yes	Yes
SIC	Yes	Yes	Yes
Year	Yes	Yes	Yes
R-square	0.15	0.16	0.15
Adjusted *R*-square	0.08	0.08	0.07
Number of observations	742	742	701

Standard errors are in parentheses; $^{+}p < 0.1$, $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.
Notes: Data pertains to recommendations made by SDSU IAC during 2000–20011. All analyses use robust standard errors. '$p < 0.1$' indicates that the probability of a false positive finding is less than 10%, under the assumptions of classical statistics. 10 of the 752 assessments are excluded from the results reported here, as the sales for these firms were recorded as 0 in the IAC database. Including these 10 assessments in our analyses does not make significant changes to the results or the inferences drawn.

model (1) is not significant at $p < 0.10$. In Table 7, for average payback of implemented recommendations, the coefficient of top management in model (1) is not significant at $p < 0.10$. In Table 8, the coefficient of top management is not significant at $p < 0.10$ in either model (1) for all recommendations or (4) for those requiring process and equipment change (where we expect top management involvement to have a greater impact).

The evidence so far on Hypotheses 1 and 2 suggests that top management involvement in general (which includes top managers with and without an operational role) seems to have little impact on the adoption of energy saving initiatives. Top management has a weak positive impact on the proportion of savings adopted, but no significant impact on the average payback of implemented recommendations, on the proportion of costs invested or on the probability of adoption of specific recommendations.

In model (2), the coefficient for top operations management is positive and significant at $p < 0.05$ in both Tables 6a and 6b. For an average assessment, involvement of a top operations manager increases the proportion of savings adopted by 13.4 percentage points, and the proportion of costs invested by 11.1 percentage points. In model (2) in Table 7 the coefficient of top operations management is positive and significant at $p < 0.10$: involvement of a top operations manager results in average payback of implemented recommendations of 0.882 years compared to 0.673 for other employees, so top operations managers are willing to wait on average 31.1% longer than other employees to recoup the implementation costs. We include top non-operations managers in "other employees", to capture the specific effect of top operations managers without confounding it with the effect of top managers in general. This introduces a bias against finding an effect of top operations management, hence making our findings conservative. The analysis excluding top non-operations managers altogether yields similar results.

Turning to the adoption of individual recommendations, the coefficient for top operations managers in model (2) in Table 8 is positive but not significant at $p < 0.10$. In model (5) of Table 8, limited to recommendations related to process and equipment change, the coefficient for top operations managers is positive and significant at $p < 0.05$. "Easy" recommendations are no more likely to be implemented if a top operations manager is involved, but those that require process or equipment change do see their implementation probability increase from 31.2% to 43.7%. Overall our results show that top operations managers have a positive impact across all adoption measures at the assessment level, in contrast to top management, and this effect is stronger for recommendations that require process or equipment change and hence need a deeper understanding of operations.

We also investigated the impact of top general managers without an operational role, in models (3) of Tables 6a, 6b, and 7, and in models (3) and (6) of Table 8. We excluded assessments that involved top operations managers, rather than include top operations managers under "other employees", to prevent our results from being biased against finding an effect for top non-operations managers. Despite this conservative approach, and in contrast to top operations managers, top non-operations managers consistently have no impact on any of our four measures of adoption. This

Table 8
Estimation results for logit model for adoption of recommendations.

Dependent variable: adopted (equals 1 if recommendation is implemented, 0 otherwise)						
	All recommendations			Process and equipment change recommendations		
	(1)	(2)	(3)	(4)	(5)	(6)
ln(Saving)	0.017	0.014	−0.007	0.364	0.368	0.290
	(0.14)	(0.14)	(0.14)	(0.25)	(0.25)	(0.25)
$[\ln(\text{Saving})]^2$	0.004	0.005	0.005	−0.013	−0.013	−0.011
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
ln(Cost)	$0.06^{*}0$	0.060^{*}	0.056^{+}	0.025	0.022	0.025
	(0.03)	(0.03)	(0.03)	(0.06)	(0.06)	(0.06)
$[\ln(\text{Cost})]^2$	-0.016^{***}	-0.016^{***}	-0.015^{***}	-0.013^{*}	-0.013^{*}	-0.013^{*}
	(0.00)	(0.00)	(0.00)	(0.01)	(0.01)	(0.01)
Top management	0.056			0.055		
	(0.11)			(0.14)		
Top operations managers		0.273			0.538^{*}	
		(0.18)			(0.24)	
Top general managers			−0.049			−0.193
			(0.12)			(0.17)
Average payback of an assessment	−0.096	−0.101	−0.124	−0.212	-0.223^{+}	-0.226^{+}
	(0.10)	(0.10)	(0.11)	(0.13)	(0.13)	(0.14)
Total savings identified/firm sales	0.000	0.000	0.000	0.000	0.000	0.000
	0.00	0.00	0.00	0.00	0.00	0.00
Total energy costs (in millions)	0.007	0.006	−0.002	0.017	0.022	0.038
	(0.05)	(0.05)	(0.05)	(0.06)	(0.06)	(0.07)
Serial position of recommendation	-0.029^{**}	-0.029^{**}	-0.033^{**}	−0.010	−0.011	−0.015
	(0.01)	(0.01)	(0.01)	(0.02)	(0.02)	(0.02)
Number of recommendations	0.005	0.006	0.006	−0.008	−0.007	−0.009
	(0.02)	(0.02)	(0.02)	(0.03)	(0.03)	(0.03)
Sales (in millions)	0.000	0.000	0.000	−0.001	−0.001	−0.001
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Employees (in thousands)	0.330	0.310	0.264	0.546	0.507	0.389
	(0.27)	(0.27)	(0.28)	(0.47)	(0.47)	(0.49)
Plant area (in million sq. ft.)	0.093	0.097	0.102	0.041	0.041	0.039
	(0.08)	(0.09)	(0.10)	(0.03)	(0.03)	(0.03)
Additional controls						
IAC	Yes	Yes	Yes	Yes	Yes	Yes
SIC	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes
Recommendation type	Yes	Yes	Yes	Yes	Yes	Yes
Psuedo R square	0.08	0.08	0.08	0.12	0.12	0.12
Log-pseudo likelihood	−3588	−3586	−3408	−1284	−1281	−1210
Number	5688	5688	5407	2261	2261	2144

Standard errors are in parentheses; $^{+}p < 0.1$, $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.
Notes: Data pertains to recommendations made by SDSU, LMU and DU IAC. Estimation method is Maximum Likelihood. Standard errors reported are using robust clustered variance covariance matrix with standard errors clustered at the assessment level. '$p < 0.1$' indicates that the probability of a false positive finding is less than 10%, under the assumptions of classical statistics.
For models (1) and (2) – 14 recommendations from the full sample related to one two digit SIC code and one recommendation type were excluded from the analyses as they predict non adoption perfectly. 77 recommendations related to 10 assessments where sales were recorded as 0 were also excluded from the analyses (as we cannot compute the variable 'Total Savings Identified/Firm Sales'). Including these 10 assessments in our analyses does not make significant changes to the results or the inferences drawn.
For models (4) and (5) – 32 recommendations from the full sample related to six two digit SIC code and one recommendation type were excluded from the analyses as they predict non adoption perfectly. 39 recommendations related to 10 assessments where sales were recorded as 0 were also excluded from the analyses (as we cannot compute the variable 'Total Savings Identified/Firm Sales"). Including these 10 assessments in our analyses does not make significant changes to the results or the inferences drawn.

implies that in examining the role of top management, one should distinguish between those with and without an operational role.

To assess the robustness of our results, we performed several diagnostic tests. Multi-collinearity is not a concern as the VIF (variance inflation factors) for our OLS models vary between 1.06 and 5.61, within accepted ranges [61]. Heteroskedasticity is not a concern, as the chi-square values for the Breusch–Pagan test [62] are not significant at $p < 0.10$. The logit specification is appropriate in models (3) and (4), as the Pearson and the Hosmer and Lemeshow goodness of fit tests [63] are not significant at $p < 0.10$. We also repeated the analyses with slightly different classifications of top managers and top operations managers, and found similar results. Finally, we initially performed this study with data from the SDSU IAC, and only later added the data from LMU and UD; the findings from the initial analysis continued to hold after adding these new data. All this taken together suggests that our findings are reasonably robust, though several inevitable limitations remain, which we discuss below.

5. Conclusions

We investigate the impact of top managers' and top operations managers' involvement in energy efficiency assessments. We find that top operations managers realize 13.4% more of energy savings identified than other employees do, and they implement a higher percentage of the investments recommended and adopt recommendations with longer payback. Having top operations managers involved increases the likelihood of adoption of more disruptive recommendations from 31% to 44%. Overall top operations managers have a positive impact on the adoption of energy efficiency initiatives, while top managers without an operational role have little or no effect. While our data do not permit definitive conclusions, this distinction between top managers and top operations managers is robust and novel.

Our results suggest that IACs and other firms and utilities that provide energy assessments should ensure that each firm has top operations managers actively involved. Currently the DOE suggests that the IACs only provide recommendations with payback less than two years, but our results suggest that they may include longer paybacks, especially if top operations managers are involved.

Our analysis is not without limitations. First, our data only cover manufacturing firms in California and Ohio. Further research should include other states to assess the role of factors such as regulations and market conditions. Second, we did not have information on demographic factors such as top management age, gender, marital status, education, and political orientation which have been shown to impact firm performance [33,34] and the adoption of environmental practices [64]. Third, we only have data from the IAC program; it would be worthwhile to examine other similar programs outside the US, and other types of program such as the ISO 50001 energy management systems standard. Also, in the IAC program implementation of the recommendations is left to the firm. An alternative model is provided by energy service companies (ESCOs), who take on financial and operational responsibility for implementing energy efficiency measures in their clients' plants. Though promising, the ESCO sector has challenges of its own [65–67].

Finally, a study such as this can never demonstrate causality. Our hypotheses provide several causal pathways by which top operations management involvement affects adoption, and our data show that a link exists. However, we do not directly observe the decision-making process within firms. It is conceivable that firms that are more energy-conscious are more likely to involve top (operations) managers. In this alternative explanation, if a firm is energy-conscious, top (operations) managers would choose to be the main contact for the audit and the firm would adopt more recommendations, but somehow top management would not contribute to that increased adoption. While conceivable in some cases, this seems unlikely to be an adequate alternative explanation for our findings. From the IAC's perspective, it is not critical whether our observations are causal or correlations; either way, the willingness of top operations managers to be involved in the assessment process increases the extent to which the IAC's recommendations are adopted. From a theoretical perspective, the distinction between causality and correlation is of course important, and would require a follow-up study with deeper access to the audited firms to be resolved more fully.

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References

[1] IPCC. Summary for policymakers. In: Metz B, Davidson OR, Bosch PR, Dave R, Meyer LA, editors. Climate change 2007: mitigation. contribution of working group III to the fourth assessment report of the intergovernmental panel on climate change. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press; 2007.
[2] Bernstein L, Roy J, Delhotal KC, Harnisch J, Matsuhashi R, Price L, et al. Industry. In: Metz B, Davidson OR, Bosch PR, Dave R, Meyer LA, editors. Climate change 2007: mitigation. Contribution of working group III to the fourth assessment report of the intergovernmental panel on climate change. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press; 2007. pp. 456–60. 475–7.
[3] Abadie LM, Ortiz RA, Galarraga I. Determinants of energy efficiency investments in the US. Energy Policy 2012;45:551–66.
[4] Trianni A, Cagno E. Dealing with barriers to energy efficiency and SMEs: some empirical evidences. Energy 2012;37:494–504.
[5] Trianni A, Cagno E, Worrell E, Pugliese G. Empirical investigation of energy efficiency barriers in Italian manufacturing SMEs. Energy 2013;49:444–58.
[6] Rohdin P, Thollander P. Barriers to and driving forces for energy efficiency in the non-energy intensive manufacturing industry in Sweden. Energy 2006;31:1836–44.
[7] Sorrell S, Schleich J, O'Malley E, Scott S. The economics of energy efficiency: barriers to cost-effective investment. Cheltenham: Edward Elgar; 2004.
[8] Anderson ST, Newell RG. Information programs for technology adoption: the case of energy-efficiency audits. Resour Energy Econ 2004;26(1):27–50.
[9] Thollander P, Ottosson M. An energy efficient Swedish pulp and paper industry – exploring barriers to and driving forces for cost-effective energy efficiency investments. Energy Effici 2008;1:21–34.
[10] Thollander P, Danestig M, Rohdin P. Energy policies for increased industrial energy efficiency: evaluation of a local energy programme for manufacturing SMEs. Energy Policy 2007;35:5774–83.
[11] European Commission. Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency, amending directives 2009/125/EC and 2010/30/EC and repealing directives 2004/8/EC and 2006/32/EC. Off J Eur Union L 2012;315:1–56.
[12] Fleiter T, Fehrenbach D, Worrell E, Eichhammer W. Energy efficiency in the German pulp and paper industry – a model-based assessment of saving potentials. Energy 2012;40:84–99.
[13] Nagesha N, Balachandra P. Barriers to energy efficiency in small industry clusters: multi-criteria-based prioritization using the analytic hierarchy process. Energy 2006;31:1969–83.
[14] Tonn B, Martin M. Industrial energy efficiency decision making. Energy Policy 2000;28:831–43.
[15] Impacts. Industrial technologies program: summary of program results for CY2005. pp. 167–70. See also: <http://www1.eere.energy.gov/industry/about/pdfs/impact2005.pdf>; 2005 [accessed 09.08.13].
[16] Industrial assessment centers database. See also: <http://iac.rutgers.edu/database/> [accessed 21.10.13].
[17] Woodruff MG, Jones TW, Dowd J, Roop JM, Muller MR. Evidence from the industrial assessment program on energy investment decisions by small and medium-sized manufacturers. Document number 97550; 1997. pp. 2138–42.
[18] Sassone P, Martucci MV. Industrial energy conservation: the reasons behind the decision. Energy 1984;9(5):427–37.
[19] Schleich J. The economics of energy efficiency: barriers to profitable investment. EIB Papers 2007;12(2):82–109. See also: <http://hdl.handle.net/10419/44886> [accessed 09.10.13] ISSN: 0257-7555.
[20] US Department of Labor – Employment and Training Administration. See also: <http://www.onetonline.org/link/summary/11-3051.00> [accessed 03.06.12].
[21] Golove WH, Eto JH. Market barriers to energy efficiency: a critical reappraisal of the rationale for public policies to promote energy efficiency. Berkeley, CA 94720: Energy & Environment Division, Lawrence Berkeley National Laboratory, University of California; 1996. LBL-38059, UC-1322.
[22] DeCanio SJ. Barriers within firms to energy-efficient investments. Energy Policy 1993;21(9):906–14.
[23] Jaffe BA, Stavins RN. The energy-efficiency gap: what does it mean? Energy Policy 1994;22(10):804–10.
[24] Thollander P. Towards increased energy efficiency [Unpublished dissertation] In Swedish industry: barriers, driving forces, and policies. Linkoping University; 2008.
[25] Ross M. Capital budgeting practices of twelve large manufacturers. Financ Manage 1986;15(4):15–22.
[26] Sorrell S, Schleich J, Scott S, O'Malley E, Trace F, Boede U, et al. Understanding barriers to energy efficiency in reducing barriers to energy efficiency in public and private organizations. Final Report. Brighton, UK: SPRU, University of Sussex; 2000. See also:, <www.sussex.ac.uk/Units/spru/publications/reports/barriers/finalsection3.pdf> [accessed 09.10.13] [chapter 3].
[27] Howarth RB, Sanstad AH. Discount rates and energy efficiency. Contemp Econ Policy 1995;13(3):101–9.
[28] Muthulingam S, Corbett CJ, Benartzi S, Oppenheim B. Energy efficiency in small and medium-sized manufacturing firms: order effects and the adoption of process improvement recommendations. Manuf Serv Oper Management. 2013;15(4):596–615.
[29] Hambrick DC, Mason PA. Upper echelons: the organization as a reflection of its top managers. Acad Manage Rev 1984;9:193–206.
[30] Hambrick DC. Upper echelons theory: an update. Acad Manage Rev 2007;32(2):334–43.
[31] Michael J, Hambrick D. Diversification posture and top management team characteristics. Acad Manage Rev 1992;35(1):9–37.
[32] Walsh JP. Selectivity and selective perception: an investigation of managers' belief structures and information processing. Acad Manage Rev 1988;31(4):873–96.

[33] Reuber AR, Fischer E. The influence of the management team's international experience on the internationalization behaviors of SMEs. J Int Bus Stud 1997;28(4):807–25.
[34] Bergh D. Executive retention and acquisition outcomes: a test of opposing views on the influence of organizational tenure. J Manage 2001;27(5):603–22.
[35] Young GJ, Charns MP, Shortell SM. Top manager and network effects on the adoption of innovative management practices: a study of TQM in a public hospital system. Strat Manage J 2001;22(10):935–51.
[36] Schroeder RG, Linderman K, Liedtke C, Choo AS. Six sigma: definition and underlying theory. J Oper Manage 2008;26(4):536–54.
[37] Brady JE, Allen TT. Six sigma literature: a review and agenda for future research. Qual Reliab Eng Int 2006;22(3):335–67.
[38] Delmas M. Stakeholders and competitive advantage: the case of ISO 14001. Prod Oper Manage 2001;10(3):343–58.
[39] Ngai EWT, Law CCH, Wat FKT. Examining the critical success factors in the adoption of enterprise resource planning. Comput Ind 2008;59(6):548–64.
[40] Jarvenpaa SL, Ives B. Executive involvement and participation in the management of information technology. MIS Q 1991;15(2):205–27.
[41] Duglio S. Energy management systems: from EN 16001 to ISO 50001. Management 2011;4(4.2):1.
[42] Van Everdingen Y, Wierenga B. Intra-firm adoption decisions: role of inter-firm and intra-firm variables. Eur Manage J 2002;20(6):649–63.
[43] Yamaguchi K. The flow of information through social networks: diagonal-free measures of inefficiency and the structural determinants of inefficiency. Soc Network 1994;16(1):57–86.
[44] Beck TE, Plowman DA. Experiencing rare and unusual events richly: the role of middle managers in animating and guiding organizational interpretation. Organ Sci 2009;20(5):909–24.
[45] Dutton JE, Ashford SJ. Selling issues to top management. Acad Manage Rev 1993;18(3):397–428.
[46] Fredrickson JW. The strategic decision process and organizational structure. Acad Manage Rev 1986;11(2):280–97.
[47] Porter ME. Competitive advantage: creating and sustaining superior performance. New York: Free Press; 1985.
[48] Stonehouse G, Pemberton J. Strategic planning in SMEs – some empirical findings. Manage Decis 2002;40(9):853–61.
[49] Kraus S, Harms R, Schwarz EJ. Strategic planning in smaller enterprises new empirical findings. Manage Res News 2006;29(6):334–44.
[50] DeCanio SJ. The efficiency paradox: bureaucratic and organizational barriers to profitable energy-saving investments. Energy Policy 1998;26(5):441–54.
[51] Delmas MA, Toffel MW. Organizational responses to environmental demands: opening the black box. Strat Manage J 2008;29(10):1027–55.
[52] Hayes RH, Abernathy WJ. Managing our way to economic decline. Harv Bus Rev 1980;58(4):67–77.
[53] Dearborn DC, Simon HA. Selective perception: a note on the departmental identifications of executives. Sociometry 1958;21(2):140–4.
[54] Hum SH, Leow LH. The perception of the strategic role of manufacturing amongst operations managers: an empirical study based on a newly industrialized economy. Int J Oper Prod Manage 1993;12(11):15–23.
[55] Muller MR, Muller MB, Glaeser FW. The DOE industrial assessment database manual, user information version 8.2. See also: <http://iac.rutgers.edu/manual_database.php>; 2004; July [accessed 03.06.10].
[56] Weiner BJ, Shortell SM, Alexander J. Promoting clinical involvement in hospital quality improvement efforts: the effects of top management, board, and physician leadership. Health Serv Res 1997;32(4):491–510.
[57] Landis JR, Koch GG. The measurement of observer agreement of categorical data. Biometrics 1977;33:159–74.
[58] Royer I. Why bad projects are so hard to kill. Harv Bus Rev. 2003;81(2):48–57.
[59] Doll WJ. Avenues for top management involvement in successful MIS development. MIS Q 1985;9(1):17–35.
[60] Benartzi S, Thaler RH. Heuristics and biases in retirement savings behavior. J Econ Perspect 2007;21(3):81–104.
[61] Chatterjee AC, Hadi AS. Regression analysis by example. 4th ed. New York: Wiley; 2006.
[62] Breusch T, Pagan A. A simple test for heteroscedasticity and random coefficient variation. Econometrica 1979;47(5):1287–94.
[63] Hosmer DW, Lemeshow S. Applied logistic regression. 2nd ed. New York: Wiley; 2000.
[64] Torgler B, Garcia-Valiñas MA. The determinants of individuals attitudes towards preventing environmental damage. Ecol Econ 2007;63(2):536–52.
[65] Goldman CA, Hopper NC, Osborn JG. Review of US ESCO industry market trends: an empirical analysis of project data. Energy Policy 2005;33(3):387–405.
[66] Lee MK, Park H, Noh J, Painuly JP. Promoting energy efficiency financing and ESCOs in developing countries: experiences from Korean ESCO business. J Clean Prod 2003;11(6):651–7.
[67] Möllersten K, Sandberg P. Collaborative energy partnerships in relation to development of core business focus and competence – a study of Swedish pulp and paper companies and energy service companies. Bus Strat Environ 2004;13(2):78–95.