Management and energy efficiency in a Chinese manufacturing cluster

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Abstract

We investigate the relationship between general and specialized management practices and energy use outcomes in a machine components manufacturing cluster in Shandong Province, China. We conduct an on-site survey of 100 firms that combines the core questions from a survey of general management practices with a new questionnaire on energy management practices, and separately collect three years of firm energy use data. Moving from the 25th to 75th percentile on management score is associated with a reduction in electricity intensity of 17% in value terms (electricity expenditure divided by output value) but only an 8% reduction in physical terms (electricity use in kilowatt-hours divided by output value). Energy management score is found to increase with general management score, and large firms tend to score highly on both measures. Interest in adopting an energy management tool increases with energy management score, while overall management score only weakly predicts interest. Modern management practices may enable organizations: 1) to identify and deploy interventions (such as load shifting) that translate into cost savings and 2) to develop specialized management practices (in this case, for energy), which in turn may increase capacity to absorb information that is of potential but uncertain value to the firm.

1. INTRODUCTION

Just as productivity of firms varies widely even within narrowly defined industries (Syverson, 2004), large spreads in energy intensity (Boyd, 2017) present an empirical puzzle. Bringing all firms closer to an industry's so-called energy intensity frontier is widely thought to deliver large energy savings and associated environmental benefits. Energy intensity benchmarks at the industry level are widely used in the design of environmental policy. The benefits of energy savings are estimated to be especially large in China, which has a vast and energy-intensive industrial sector responsible for approximately 55% of the nation's energy use (National Bureau of Statistics, 2013), equivalent to more than 10% of the global total (International Energy Agency, 2014).

Energy efficiency investments are widely thought to offer returns that far outweigh the costs of implementing them. Empirical evidence that many of these allegedly low-hanging fruit are not harvested is referred to as the energy efficiency gap (Jaffe and Stavins, 1994; Allcott and Greenstone, 2012; Gerarden et al., 2015), prompting a rich inquiry into the potential existence of difficult-to-measure costs associated with adoption (DeCanio and Watkins, 1998) as well as behavioral explanations (Allcott and Wozny, 2014). Efforts to accelerate the uptake of energy efficiency investments have revealed that firm characteristics are important predictors of adoption (DeCanio, 1998). For example, firm performance, location, and industry were found to correlate with participation in a generic and voluntary energy-saving program for lighting (DeCanio and Watkins, 1998). A study by Anderson and Newell (2004) of firm responses to a government energy audit found that adoption decisions implied hurdle rates of 50-100%. A randomized control trial in India

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showed that plants provided with an energy audit invested far less in energy efficiency than was estimated to be profitable (Ryan, 2015). Despite abundant evidence of an energy efficiency gap, our understanding of what explains adoption and impact of energy saving technologies and practices in firms remains limited.

A growing body of evidence has suggested that management may be at least partially responsible for firm-level differences in energy efficiency. In a sample of firms in the United Kingdom, Bloom et al. (2010) found that a higher management score was associated with a reduction in energy intensity (energy expenditure per value of output) of 17.4% when moving from the 25th to the 75th percentile on management score. A study for the U.S. suggested a more complex relationship, with most management techniques associated with lower energy intensity, but an emphasis on generic targets, conditional on other management practices, was found to be correlated with higher energy intensity (Boyd and Curtis, 2014). Martin et al. (2012) studied the relationship between "climate friendly" management practices, organizational structure, and energy efficiency in U.K. firms, and found adoption of "climate friendly" management practices is higher if the firm has an environmental manager with direct links to the CEO. Here, we take the inquiry into management practices and the energy paradox to mainland China, and extend it to consider the relationship among general and specialized management practices and energy use outcomes in both physical and financial terms. We further consider how these practices affect a firm's interest in adopting an energy-saving technology.

The setting for our study is a machine components manufacturing cluster in Shandong province, China, in which electricity is the dominant energy input to production. It is the first study, to our knowledge, to evaluate general management (based on the World Management Survey questionnaire), energy management (based on best practice domestic industry standards), and energy use in both physical and value terms at the firm level. While our sample size, at 100 firms, is on the smaller side for statistical inference, we control for location (by selecting firms within a single prefectural city), industry, and a firm's energy-intensive industrial process (either metal machining, casting, and forging). Most of the firms in our sample are small and medium-sized enterprises, however, we did not screen for size as our objective was to survey the entire population, resulting in the inclusion of several larger firms. When possible, we display the underlying data to allow for a richer understanding of heterogeneity and patterns in the sample. We supplement our statistical analysis of the cross-section and interpretation of the results with observations and discussion from the on-site interviews.

Our study yields three main findings. First, consistent with prior studies, we find evidence that management, both general and energy specific, is correlated with lower electricity use intensity in firms. We further show that management is associated with a lower imputed electricity cost, and provide evidence that firms adjusted equipment utilization rates and shifted load temporally to take advantage of time-varying electricity prices. Second, energy management practices are always accompanied by strong general management practices. None of the firms receive a high energy management score but low general management score, while the reverse occurs frequently, and both sets of practices tend to be stronger in larger firms. Third, a high energy management score is positively associated with a firm's interest in adopting an energy management tool, suggesting that specialized management practices may enhance a firm's cognition of potential cost-saving opportunities.

2. BACKGROUND AND EMPIRICAL SETTING

2.1 Background

There is great interest in reducing the energy intensity of manufacturing, both to limit waste and mitigate energy-related environmental damages. The manufacturing sector accounts for over two-thirds of global end-use energy demand (International Energy Agency, 2014). While much of this energy use is concentrated in industries with high energy intensity (iron and steel, cement, refined oil, chemical products, and mining and metals production), high value-added manufacturing activities account for substantial shares. Energy used in high value-added manufacturing primarily takes the form of electricity, an energy carrier that is generated from primary fuels, and accounts for over 10% of China's total energy use (National Bureau of Statistics, 2013). Globally and especially in China, primary fuels used to generate electricity remain dominated by fossil fuels, especially coal, which when combusted generate local air pollutants and carbon dioxide, a major greenhouse gas responsible for global climate change.

There is abundant evidence that well-managed firms show superior performance on a wide range of measures. A number of studies have established the relationship between management and productivity in manufacturing firms (Mefford, 1986; Ichniowski et al., 1997; White et al., 1999; Bloom and Van Reenen, 2007). Studies by the World Management Survey based on interviews with firms across many countries have consistently found a positive correlation between management practices and productivity (Bloom and Van Reenen, 2007; Bloom et al., 2012). The causal effect of management practices on productivity in firms has been established in randomized controlled trials in India (Bloom et al., 2013) and in Mexico (Bruhn et al., 2017). Well-managed firms are also found to comply with labor standards (Distelhorst et al., 2016), use energy efficiently (DeCanio and Watkins, 1998; Bloom et al., 2010), and clean up the pollution they generate (Boyd and Curtis, 2014), relative to poorly-managed firms.

The main contribution of our study is to consider the relationship between general management practices, specialized energy management practices, patterns of firm-level energy use, and interest in the adoption of an energy management tool. Previous studies have considered the relationship between management practices and energy (Bloom et al., 2010; Boyd and Curtis, 2014), between specialized "climate-friendly" management practices and energy intensity (Martin et al., 2012), and between firm characteristics and management innovation (Mol and Birkinshaw, 2009). We are not aware of any literature that has considered these concepts and outcomes within a single population of firms. We further extend this inquiry to mainland China, complementing previous work largely focused on advanced industrialized economies. The firms we focus on are in many cases directly or indirectly producing for export markets. Given that these firms are relatively small and operate far upstream with low value added and minimal international exposure, they represent an understudied population that makes a sizable aggregate contribution to global energy use and environmental quality in developing countries.

2.2 Empirical Setting

We study a cluster of 100 co-located machine component manufacturing firms in Jinan city, Shandong province, China (location shown as in **Figure 1**). All firms in the sample fall within a 50-mile radius and are spread across the city's eight districts/counties, making all firms comparable on dimensions of local climate (which can significantly impact energy use), governance at the city level and above (thus policy environment is common to all firms), and market conditions (including electricity price schedules and labor force composition). Jinan city also has a distinct industrial history, as some industrial processes and product types have remained unchanged for thousands of years. Firms in our population represent seven two-digit industries and were chosen for similarity in their production processes (all firms are involved in metalworking, and can be divided into three subcategories: machining, casting, and forging). Many of the firms in our sample manufacture multiple products using a fixed set of production equipment that is powered by electricity. Two-thirds of the firms included in the final data set used in this analysis are single-plant firms. Our unit of analysis is the plant. Photographs (taken with permission) of the physical setting and production floor at several of the firms in our sample are shown in **Figure A1** to **Figure A4**.

Electricity use and production information for all firms over three years (2013, 2014, and 2015) was obtained through a survey disseminated by our local partner in Jinan city, a non-governmental organization that has extensive prior experience providing information to industrial firms on energy saving opportunities, participating in government consulting projects, and developing national energy management standards. Electricity consumption data, including the level during peak demand periods, off-peak periods, and total consumption, was obtained at monthly resolution for all three years. Firms were assured that raw data provided would be kept strictly confidential. Our local partner is not involved in regulatory enforcement and regularly interacts with government offices at the county level as well as with firms directly, leading to a high degree of trust and raising the chances of obtaining data that represent an honest collection effort. Firm submissions were cross-checked against metered electricity bills for a subsample of firms to ensure consistency. We were unable to verify reported consumption of other energy types, which represented a modest share of the overall total, and therefore we focus on electricity in this study. Other energy types were largely used for space heating and not substitutable with electricity in core production processes.

A two-part survey covering management and energy management was designed and administered by a collaborative team including an analyst, two associates, and one junior partner from the China offices of a global management consultancy and researchers from the Massachusetts Institute of Technology and Tsinghua University. The team administered the survey with logistical support from our local Shandong partner. Over a period of five weeks, two groups (each comprised of one

Source: Wikipedia (Jinan)

Figure 1. Location of Jinan city in China.

MIT or Tsinghua researcher and one consultancy analyst or associate) conducted on-site interviews on general management and specialized energy management practices in the Chinese language at 100 firms over two months in March and April 2016. All team members attended a one-day orientation on survey administration, followed by a mock interview round to ensure consistency in teams' understanding of the survey questions and scoring procedure. The teams visited two to four sites per day, depending on travel time between sites, and interviewed one member of the company's general management and, when available, one energy specialist. Completing the full interview (including its general management and energy management components) required approximately one hour.

The management questionnaire follows the methodology of the World Management Survey very closely, with minor adjustments to localize concepts to the Chinese context. The survey included multiple questions in four categories (operations, targets, monitoring, and incentives) each of which was scored on a 1-5 scale by the interviewer. Scoring outcomes were not shared with the interviewee. Starting with a Chinese translation of the management survey based on Bloom and Van Reenen (2007), question translations were vetted for accuracy of meaning and potential for misinterpretation by multiple Chinese speakers within the global consultancy, MIT, and local Shandong teams. Prior to fielding the survey, we performed a dry run of the full interview with one company and made subsequent adjustments to reflect managers' feedback and shortened the questionnaire to avoid running into time constraints.

The energy management questionnaire incorporates general requirements from China's national standard for energy management GB/T 23331, which closely follows the international energy management standard ISO 50001. Questions attempted to measure the firm's general awareness and experience with energy saving measures, as well as the existence and extent of the company's internal energy management system. A copy of the energy management questionnaire is provided in **Table A1**. Both general management scores and energy management scores are calculated as unweighted averages of scores given on individual questions.

Interviewers began by asking general management questions to a member of firm's middle management or above. Energy management questions were answered by either the manager (if no energy management staff was available), otherwise a specialized energy manager was interviewed. At the end of the management and energy management interviews, the firm representative was asked if they would be interested in adopting an online platform that identifies energy saving opportunities, known as the Resource Efficiency Deployment Engine or RedE, developed by the global consultancy. The platform guides the user to input information about the firm's equipment, processes, energy use patterns, and energy expenditures, and returns a list of "levers" based on their estimated potential to reduce expenditures on energy use. The lever set provided to the firm is selected from a database of energy-saving interventions informed by a combination of engineering estimates and prior implementation across a wide range of industries. The list includes many process-based changes that incur no up-front cost. Each lever is accompanied by an estimate of the cost savings and payback period. The firm is then responsible for introducing the recommended changes, for instance by altering existing processes and practices, adjusting equipment settings, or investing in more energy efficient equipment.

Of the original set of 100 firms for which we obtained both management scores and energy use information, we dropped three firm outliers that either had very intermittent production, were involved solely in assembly (very low energy intensity), or reported dramatic shifts in energy intensity between 2014 and 2015. We further dropped seven firms that did not fall into the three process categories related to metalworking, as discussed above.

3. RESULTS

3.1 Data and Descriptive Statistics

The firms in our sample were chosen for similarity in the basic energy-intensive production processes they employ. Firm size varies widely, measured both in terms of the number of employees and sales value. The average firm age in the sample is 23 years, with the youngest firm 2 years old and the oldest 106. Just under 15% of the firms in our sample are state owned, among them firms overseen by the central, provincial, and city government. The average share of electricity consumption in total energy use (calculated on the basis of heating value) is 70%.* Many of the firms in our sample directly export their products, with an average share of product sales exported reported at 14%. Over 63% of the firms in our sample did not engage in any exporting activity.

We find that once we account for differences in energy-intensive production processes, the standard deviation of energy use is smaller than the mean for all three process groups (metal machining, casting, and forging). Casting is the most electricity intensive, as it involves melting metal, while metal machining is the least energy intensive. Interestingly, these firms belong to multiple two-digit industry categories, despite having very similar production processes within the three firm groups. Looking within two-digit and even four-digit industry categories, we find substantial differences in energy-using processes among firms, underscoring that industry code may not be the best indicator of a firm's relative energy intensity.

Table 1. Summary statistics for the 90 firms from 2013 to 2015.

	Mean	**Stdev**	**Min**	**Max**
Overall management	3.1	1.0	1.0	4.9
Energy management	1.9	1.1	1.0	5.0
Sales (million CNY)	294.6	722.8	300	408.4
Employees	482.2	1029.8	10	6000
Firm age	23.7	21.4	2	106
Export share	0.14	0.24	0	1
Electricity consumption (GWh)				
Casting firms (24 obs)	39.5	62.6	1.5	207.2
Forging firms (30 obs)	1.6	2.9	0.06	11.3
Metal machining firms (214 obs)	3.3	7.0	0.04	35.1
Electricity intensity (kWh/yuan)				
Casting firms (24 obs)	1097.4	789.2	136.9	2982.0
Forging firms (30 obs)	616.8	464.0	71.6	1978.3
Metal machining firms (214 obs)	149.4	134.4	9.5	618.3

Compared to a national sample of firms (year 2011, sales larger than 20 million yuan) in the same industries from the China Industrial Census, the firms in our sample are not significantly different in terms of sales, number of employees, or the proportion of state-controlled enterprises. **Table 1** shows summary statistics of the firms for which we have complete management survey and electricity use data.

* We believe that firms' self-reported energy use for energy types other than electricity was not reported consistently across firms, with some firms including electricity consumption in reported totals and others omitting it. The calculation here is based on the average for the subset of firms that report electricity consumption smaller than total energy use (in units of tons of coal equivalent, a standard measure of energy in China).

3.2 Management and Energy Use

Figure 2 shows the kernel density of normalized electricity intensity in value terms (log deviations from the industry mean) for the sample of metal machining firms with management score in the bottom quartile (badly managed) and the top quartile (well managed). The two distributions have limited overlap, and the badly managed firms have substantially higher energy intensity. We caution that our sample size is relatively limited, with each distribution representing approximately 20 firms. Nevertheless, the difference in energy intensity between the badly managed and well managed firms is striking, with the distribution for the latter much narrower than the former.

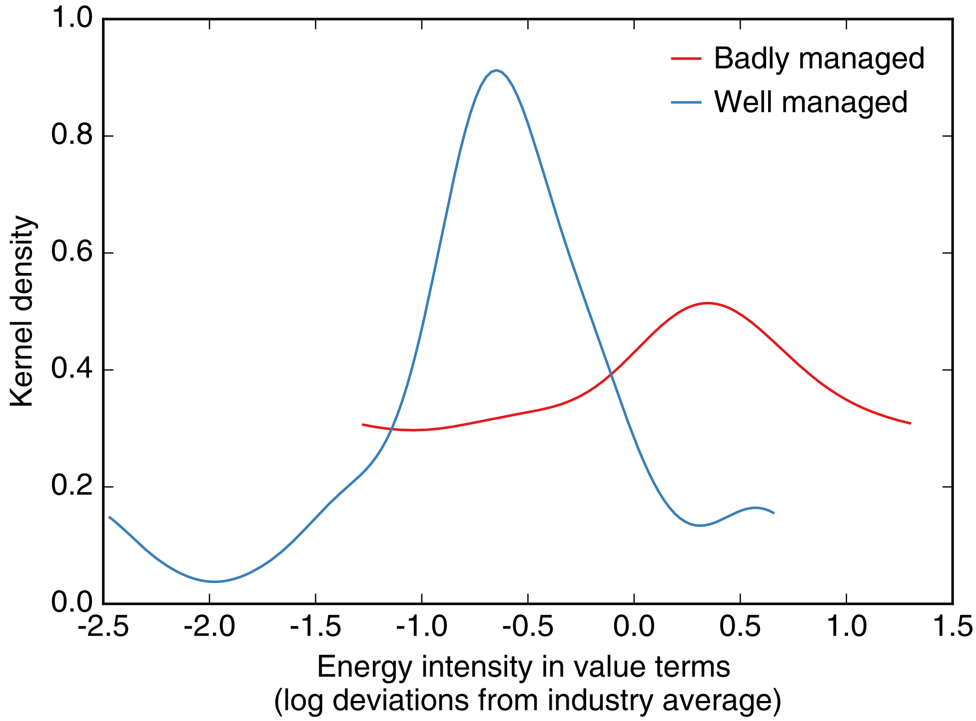


Figure 2. Relationship between management practices and energy intensity for metal machining firms.

Notes: The graph shows kernel density plots of normalized electricity intensity in value term (log deviations from industry mean) for the sample of metal machining firms with management score in the bottom quartile (badly managed) and the top quartile (well managed).

As shown in **Figure 3**, there is a negative correlation between management and electricity use intensity, with moving from the 25th to 75th percentile in management score associated with a reduction in electricity use intensity of 17% (in value terms) and 8% (in physical terms). The stronger correlation with the value measure is consistent with the possibility that management effort is being directed toward minimizing energy cost but not physical use *per se*. Despite greater homogeneity in location, industry, and processes employed relative to the U.K. sample, the spread is very similar to that observed for U.K. firms (at 17.4% in Bloom et al. (2010)). For energy management score, the correlation with electricity use intensity is much lower as shown in **Figure 4**. This is perhaps unsurprising, as firms that tend to be more energy intensive may also have stronger incentives to invest in developing energy management practices.

We regress electricity intensity on management level and a range of other firm characteristics:

$$EI_{i,t} = \beta_M * M_i + \beta_Y * ln\, Y_{i,t} + Z_i + \delta_t + \epsilon_{c,t} \tag{1}$$

where electricity intensity $EI_{i,t}$ is related to management score M_i, firm output value $Y_{i,t}$, a year dummy δ_t, and a vector of firm-specific controls Z_i including the firm's main energy-intensive production process (metal machining, casting, forging), the firm's voltage level (which affects the firm's electricity price, as will be described below), firm age, and noise controls.

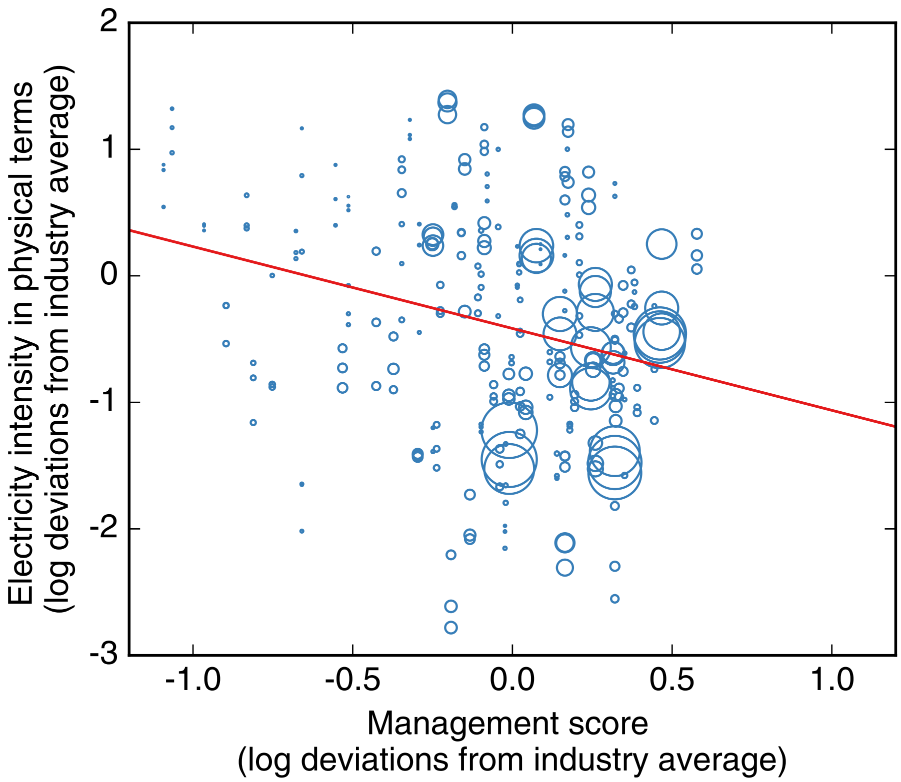
As shown in **Table 2**, management is strongly associated with lower average energy intensity for the firms in our sample. Once a firm's output size is included in the regression, we find that the coefficient on management remains negative, but loses its significance. In the preferred specification, which includes controls for process, firm age, voltage level, and noise, we find that while the coefficient on energy management score is not significant either, while the coefficient on firm size is large and highly significant.

3.3 Management and Unit Electricity Cost

There are several operational adjustments that firms can make to influence their unit electricity cost. The first is load shifting, or running facilities during hours when electricity is less expensive. A second involves increasing utilization, conditional on transformer capacity, which spreads the fixed cost of the transformer over more units of output.

The firms in our sample face an identical schedule of electricity prices, which depends only on the time of electricity use and the size of a firm's transformer. The price schedule is described in **Table 3**. There are four time-of-use based categories. Summit hours are 10:30 - 11:30, 19:00 - 21:00 from June to August, peak hours are 8:30 - 11:30 and 16:00 - 21:00 from September to May and 8:30 - 10:30, 16:00 - 19:00 from June to August, base hours are 11:30 - 16:00, 21:00 - 23:00, and 7:00 - 8:30, and valley hours are overnight, 23:00 - 7:00. The electricity price during the valley hours is only half of the base price and one third of the peak hour price, translating into potentially large savings for firms that use electricity during these hours. Many of the firms we visited stated that they were taking advantage of the low valley hour electricity price by shifting a portion of production to the nighttime hours.

In this context, it is plausible that management is helping firms identify load-shifting opportunities, while utilization is largely determined by exogenous (product market) conditions that in turn affect electricity requirements. We ask whether management is correlated with a lower per-unit electricity cost, conditional on firm size and other characteristics using the regression similar to Equation (1) with the imputed electricity cost as a dependent variable. **Table 4** shows that firms with good management practices face lower per-unit electricity costs. We find that management score is



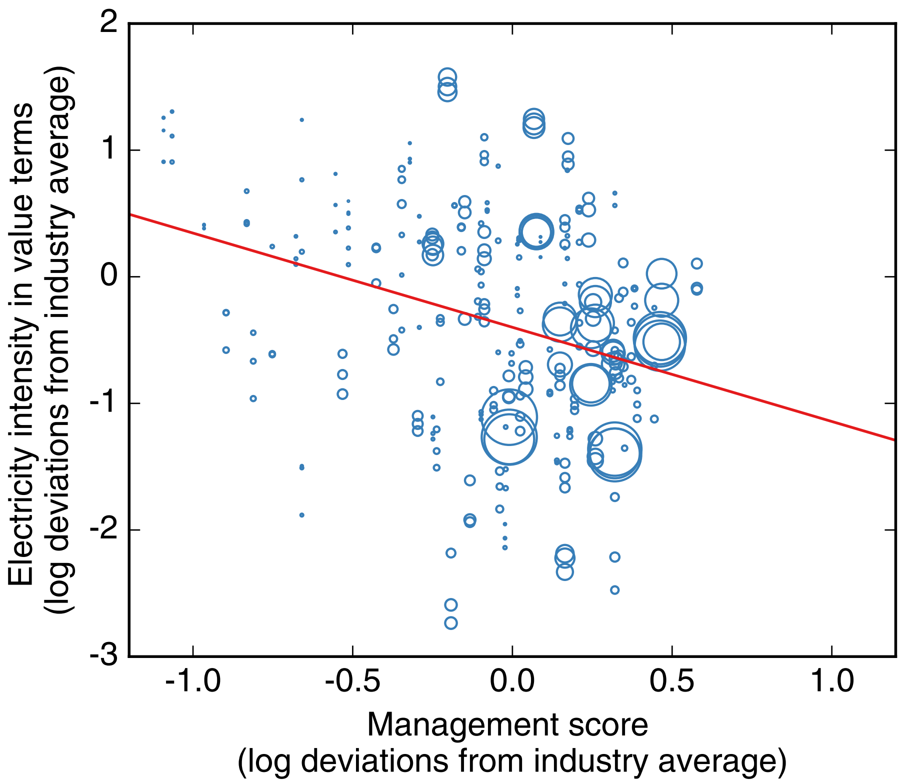


Figure 3. Energy intensity (physical and value terms), management and size at the firm level.

Notes: The graph shows a scatter plot of the residuals of a regression of log(energy expenditure / sales) on process dummies against the residuals of a regression of the management score on the same industry dummies. Circles represent firm size in terms of sales value. We include the data for all three years.

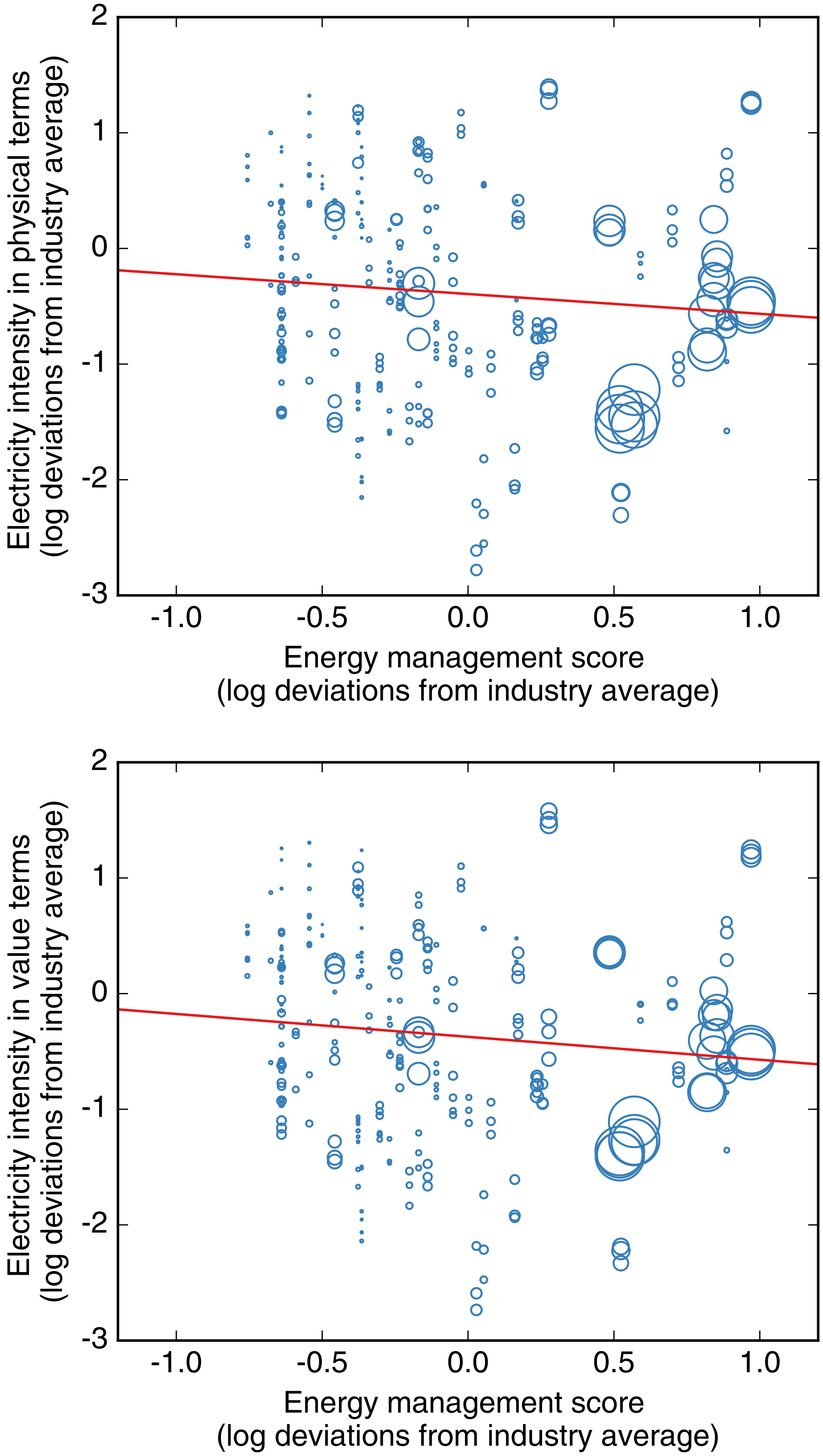


Figure 4. Energy intensity in physical (top) and value (bottom) terms, energy management, and size of firms in our sample.

Notes: The graph shows a scatter plot of the residuals of a regression of log(energy expenditure / sales) on process dummies against the residuals of a regression of the energy management score on the same industry dummies. Circles represent firm size in terms of sales value. We include the data for all three years.

Table 2. Correlation between management practices and electricity intensity (in value terms), controlling for firm characteristics.

	Energy intensity in physical terms (kWh/10,000 yuan)				Energy intensity in value terms (yuan/10,000 yuan)			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Management	-59.6**	-51.1**	-9.6		-54.7***	-50.1**	-21.4	
	(24.6)	(27.7)	(32.1)		(19.0)	(21.4)	(24.4)	
Energy management				-5.8				1.8
				(44.3)				(30.8)
log (sales)			-58.8**	-59.2***			-40.7**	-47.6***
			(26.5)	(20.1)			(19.1)	(15.3)
Year controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Process controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm age controls	No	Yes	Yes	Yes	No	Yes	Yes	Yes
Voltage level controls	No	Yes	Yes	Yes	No	Yes	Yes	Yes
Noise controls	No	Yes	Yes	Yes	No	Yes	Yes	Yes
Observations	271	253	253	253	271	253	253	253
Firms	90	85	85	85	91	85	85	85

Notes: The dependent variable is energy consumption in kWh over sales (unit: 10,000 yuan) for regressions (1) to (4) and energy expenditure (yuan) over sales (unit: 10,000 yuan) for regressions (5) to (8). We treat sales as gross output value because all the firms report that they only produce when there is an order and keep a very low level of inventory for final products. 'Management' is the unweighted average score of the 19 questions on management practices, and 'Energy management' is the unweighted average score of the 10 questions on energy management practices. Noise controls are a set of variables capturing interview characteristics: duration of the interview and the patience and willingness to share information of the interviewee as perceived by the interviewer. Standard errors are clustered at the firm level (i.e. robust to heteroscedasticity and autocorrelation of unspecified form) and reported in parentheses below coefficients: * significant at 10%; ** significant at 5%; *** significant at 1%.

negatively correlated with per-unit electricity expenditure and significant at the 10% level. Moving from the 25th to 75th percentile on management score is correlated with an 8% decrease in per-unit electricity cost. We further find that firms with a higher management score tended to report both load shifting and higher transformer utilization rates.

Table 3. Shandong electricity price structure for large industrial users.

Voltage level (VL)	**Price per kWh**					**Monthly fixed cost based on transformer capacity (yuan/kVA)**
	Benchmark price (yuan/kWh)	Time-of-use pricing multiplier				
		Summit hours	Peak hours	Base hours	Valley hours	
1 kV $\leq VL \leq$ 10 kV	0.6646	1.7	1.5	1	0.5	28
35 kV $\leq VL <$ 110 kV	0.6496	1.7	1.5	1	0.5	28

Sources: Shandong Bureau of Commodity Price (April 2015).
Note: The benchmark price is occasionally changed by the Shandong Bureau of Commodity Prices, and changes apply uniformly to the population of firms. Summit hours (10:30 - 11:30, 19:00 - 21:00 from June to August), peak hours (8:30 - 11:30, 16:00 - 21:00 from September to May; 8:30 - 10:30, 16:00 - 19:00 from June to August), base hours (11:30 - 16:00, 21:00 - 23:00, 7:00 - 8:30), and valley hours (23:00 - 7:00).

Table 4. Correlation between electricity cost per kWh and management practices

	Imputed electricity cost (yuan/kWh)			
	(1)	(2)	(3)	(4)
Management	-0.034*	-0.039*	-0.051*	
	(0.02)	(0.02)	(0.03)	
Energy management				-0.016
				(0.04)
			0.018	0.001
log (sales)			(0.01)	(0.02)
Year controls	Yes	Yes	Yes	Yes
Process controls	Yes	Yes	Yes	Yes
Firm age controls	No	Yes	Yes	Yes
Voltage level controls	No	Yes	Yes	Yes
Noise controls	No	Yes	Yes	Yes
Observations	271	253	253	253
Firms	91	85	85	85

Notes: The dependent variable is imputed electricity cost (yuan/kWh). 'Management' is the overall score based on the 19 questions on management practices, and 'Energy management' is the overall rating based on the 10 questions on energy management practices. Noise controls are a set of variables capturing interview characteristics: duration of the interview and the patience and willingness to share information of the interviewee as perceived by the interviewer. Standard errors are clustered at the firm level (i.e. robust to heteroscedasticity and autocorrelation of unspecified form) and reported in parentheses below coefficients: * significant at 10%; ** significant at 5%; *** significant at 1%.

3.4 General and energy-specific management capabilities

We now consider the relationship between general management and specialized energy management capabilities. We find that energy management is strong only when general management is strong, but not the reverse. Firms size is strongly correlated with higher general management capabilities as well as specialized energy management scores. The relationship between general management score, energy management score, and firm size is shown in **Figure ??**.

We examine the predictors of both general management score and energy management score using the regression below.

$$M_i = \beta_Y * ln\, Y_{i,t} + \beta_{exp} * \theta_i^{exp} + \beta_{prod} * D_i^{prod} + \beta_{family} * D_i^{family} + \beta_{state} * D_i^{state} + \epsilon_i \qquad (2)$$

where M_i represents firm's management score (or energy management score). Firm output value $Y_{i,t}$, export share in sales θ_i^{exp}, product type dummy D_i^{prod} (customized or standard products), ownership dummies (D_i^{family} and D_i^{state}) as well as a vector of firm-specific controls Z_i (similar to Equation 1) are included as independent variables.

The results are shown in **Table 5**. We find that in addition to firm output value, several other firm-specific characteristics are associated with management score. Interestingly, we find that a

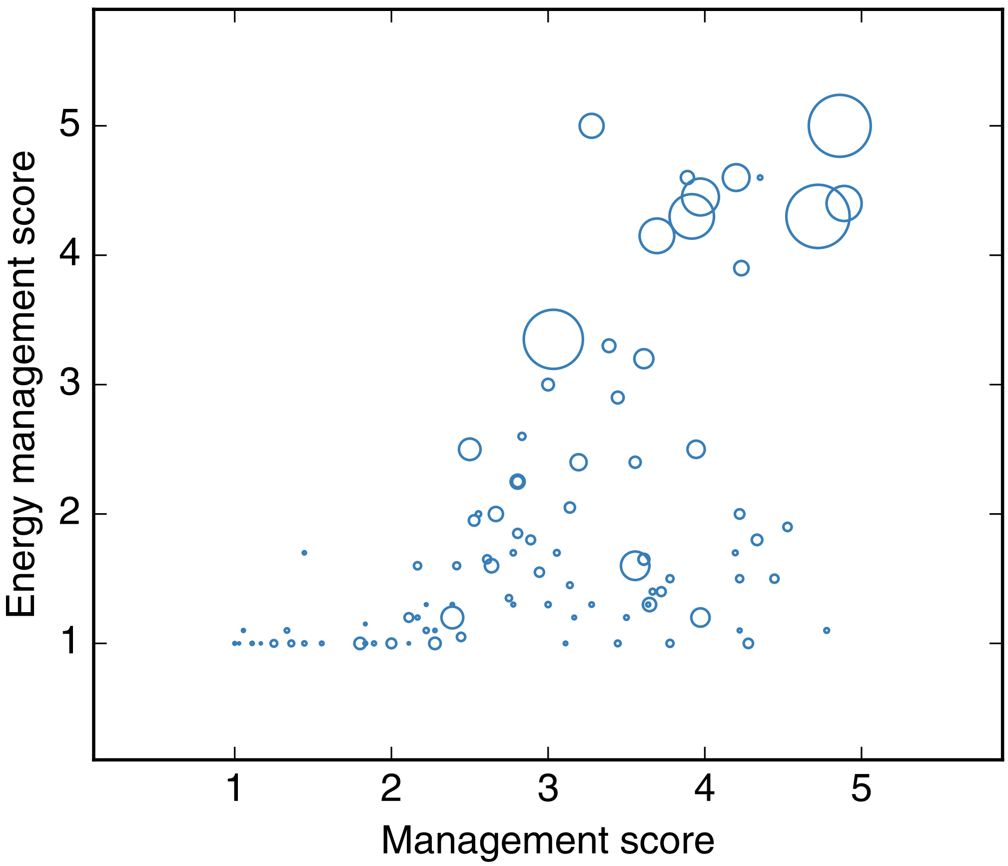


Figure 5. Correlation between management and energy management capacities.

Notes: Circles represent firm size in numbers of employees.

firm's export share in sales is positively correlated with its management practice level, but not with its energy management practice level. The observation that good management practices are associated with exporting is consistent with prior work (Tanaka, 2016). The fact that exporting is positively associated with general management score but not specialized energy management score, is plausible as in China it is the government that encourages firms, particularly state-owned enterprises, to adopt energy management systems. In the context of export oriented buyer-supply relationships, however, energy efficiency may be far less important. Firms may even have incentives to hide energy efficiency information, as divulging it to suppliers could lead buyers to push for lower purchase prices (a concern expressed by firm representatives during several of the interviews). We did not find a significant relationship between firms making customized products (rather than standardized products) and higher management scores. Similar to the finding in Bloom and Van Reenen (2007) that family-owned firms with primogeniture are less well managed, we find that firms with multiple family members on the management team are less well managed, and this effect is significant at the 1% level.

Table 5. Correlation between management practices and firm characteristics

	Management practices					Energy management practices				
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
log (sales)	0.26***	0.28***	0.22***	0.26***	0.25***	0.47***	0.47***	0.47***	0.43***	0.43***
	(0.06)	(0.05)	(0.06)	(0.07)	(0.06)	(0.06)	(0.07)	(0.06)	(0.07)	(0.07)
Export share in sales	0.82**	1.02***	0.80**	0.82**	1.01***	0.00	-0.14	0.00	0.04	-0.11
	(0.35)	(0.37)	(0.32)	(0.35)	(0.34)	(0.21)	(0.24)	(0.21)	(0.21)	(0.24)
Customized products		0.03			0.08		-0.04			-0.03
		(0.41)			(0.58)		(0.27)			(0.23)
Multiple family members in management			-0.48***		-0.45***			0.18		0.10
			(0.19)		(0.18)			(0.13)		(0.14)
State ownership				-0.03	-0.16				0.43	0.46
				(0.29)	(0.28)				(0.29)	(0.30)
Process controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm age controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Voltage level controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Noise controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firms	85	83	85	85	83	85	83	85	85	83

Notes: The dependent variable is management scores for regression (1) to (5) and energy management scores for regression (6) to (10). We treat the sales as gross output value because all the firms report that they only produce when there is an order, and they keep very low level of inventory for final products. 'Management' is the overall score based on the 19 questions on management practices, and 'Energy management' is the overall rating based on the 10 questions on energy management practices. Noise controls are a set of variables capturing interview characteristics: duration of the interview and the patience and willingness to share information of the interviewee as perceived by the interviewer. Standard errors are clustered at the firm level (i.e. robust to heteroscedasticity and autocorrelation of unspecified form) and reported in parentheses below coefficients: * significant at 10%; ** significant at 5%; *** significant at 1%.

3.5 Management capabilities and technology adoption

We now turn to assess the relationship between pre-existing firm characteristics and the willingness of the firm's leadership adopt an online energy management tool free-of-charge that offers each firm an individualized menu of opportunities to improve its energy use efficiency. The online tool requires registering the company in a database and inputing detailed information about the firm's existing energy use patterns, which the system then uses to identify potential energy saving opportunities and to estimate the magnitude of associated financial savings and payback period. The tool identifies both operational changes with zero up-front cost as well as a range of possible investments that pay back over a period of months or years.

We estimate a logit regression with the dependent variable equal to one if the firm expresses interest, and zero if the firm has no interest in adopting the tool. The form of regression is similar to Equation 2, except the firm's willingness to adopt the tool is the dependent variable and management scores are included as independent variable. Of the firms in the sample, 39 firms were interested in adopting the tool, while 46 firms indicated no interest. Predictors of a firm's expressed interest in adopting the tool are shown in **Table 6**.

We find that a firm's willingness to adopt the tool is strongly correlated with its management and energy management score. This might be explained by the fact that firms with higher management and energy management score likely acknowledge the value of efficient use of energy and are more willing to adopt recommendations. Firm size is significant when only management is included in the regression; once energy management score is included, the coefficient on firm size remains positive but loses significance. There is a significant positive relationship between firms making customized products (rather than standardized products) and willingness to adopt. We speculate that this could reflect the role of maintaining flexibility in the face of changing requirements or intermittent orders. State firms are less willing to consider external advice, perhaps because internal approvals are typically required, which can be complex and time-consuming.

Table 6. Correlation between the interest to receive the training and management.

	Interest to receive the training			
	(1)	(2)	(3)	(4)
Management	0.79*	1.38**		
	(0.42)	(0.59)		
Energy management			1.60***	1.95***
			(0.60)	(0.72)
log(sales)	0.27	0.46*	-0.54	-0.39
	(0.19)	(0.26)	(0.36)	(0.37)
Export share in sales		-0.11		0.93
		(1.21)		(1.15)
Customized products		4.85***		5.19***
		(1.65)		(1.74)
Multiple family members in management		1.22		0.23
		(1.07)		(0.82)
State ownership		-1.56*		-2.40*
		(0.94)		(1.26)
Process controls	Yes	Yes	Yes	Yes
Firm age controls	No	Yes	Yes	Yes
Voltage level controls	No	Yes	Yes	Yes
Noise controls	No	Yes	Yes	Yes
Firms	85	83	85	83

Notes: The dependent variable is the interest to receive the training. We treat the sales as gross output value because all the firms report that they only produce when there is an order, and they keep very low level of inventory for final products. 'Management' is the overall rating of the 19 questions on management practices, and 'Energy management' is the overall rating of the 10 questions on energy management practices. Noise controls are a set of variables capturing interview characteristics: duration of the interview and the patience and will of disclosure of the interviewee as perceived by the interviewer. Standard errors clustered at the firm level (i.e. robust to heteroscedasticity and autocorrelation of unknown form) are reported in parenthesis below coefficients: * significant at 10%; ** significant at 5%; *** significant at 1%.

4. CONCLUSIONS

Our finding that better-managed firms tend to be less energy intensive is consistent with observations from other settings (Bloom et al., 2010; Boyd and Curtis, 2014; Martin et al., 2012). We extend previous studies by comparing the relationship between management and physical and value measures of energy intensity. We find that management may be particularly effective at helping firms identify ways to reduce their average energy cost, which is only partially a result of reductions in physical energy use. Physical energy use, however, is most directly correlated with environmental damages, the costs of which are largely external to the firm (and not reflected in energy prices).

Our analysis points to several reasons why the notion of moving all firms to a theoretical energy efficiency frontier is perhaps too idealistic. First, the frontier must be carefully defined. We find evidence that monetary savings translate into less than proportional energy savings. If environmental impact is the main concern, better management directed toward realizing cost savings will not necessarily lead to proportional improvements on environmental metrics. Pollution pricing or regulation would still be required. Another definitional issue relates to industry classification, which we find that even the four-digit level may be too broad to identify a common set of energy-saving best practices.

Second, our interviews revealed significant variation in the importance firms attached to energy management. Reasons we noted across firms included principal-agent problems (individuals operating equipment were not directly rewarded for energy efficiency nor were they knowledgeable about savings opportunities), low salience (management, in some cases a single individual, showed limited interest in energy management as a source of savings for the firm), and misaligned incentives (firms that demonstrated energy savings would be required to pass savings along to buyers).

Third, even though they share the same industry, location, and processes, firms in our sample varied in terms of their access to input and output markets, position in the supply chain, complexity and variety of products, and ownership. We found that these characteristics often translated into striking differences in the internal organization and priorities of the firm, as well as external demand fluctuations that determine the timing of energy needs. While the energy efficiency frontier is not usually defined with respect to these differences, they may impose differentiating constraints on firms' ability to reduce the intensity of energy use.

When studying the energy productivity of firms, we find evidence that grouping based on a firm's core process may be more useful than the sector classification. Even at the four-digit level, firms can produce a wide variety of products, using an even greater variety of processes. For instance the same firm might produce screws, flanges and pipes; another firm in our sample produced components for railway wagons, large cranes, and large mechanical presses. Moreover, a firm that produces two products classified as different based on industry code may actually use a single machine in almost exactly the same way to produce both.

We note that well-managed firms are found to excel on a variety of dimensions: productivity (Mefford, 1986; White et al., 1999; Bloom and Van Reenen, 2007), compliance with labor standards (Distelhorst et al., 2016), energy efficiency (Bloom et al., 2010), and environmental protection (Martin et al., 2012; Boyd and Curtis, 2014). We examine the relationship between general management capabilities and specific (in this case, energy management) capabilities, and find evidence that general management capabilities nearly always accompany energy management capabilities. Firms that are better managed on both general and specific measures also tend to be larger than other firm types. Our findings are consistent with the possibility that firms that are well-managed in a general sense are better positioned to develop layers of management competencies within the organization. In this conception, management practices serve a cognitive function for the organization, guiding the firm to identify and act on relevant information and cost reduction opportunities. More work is needed to test these notions in the field.

We further find that it is energy management score, and not general management score, that is associated with interest in adopting an energy management tool. This observation suggests that specific knowledge of energy and the capacity to track and adjust its use will lead firms to seek and absorb new information or interventions that could enable them to further optimize. Our interviews suggested that establishing an energy management system carries fixed costs that require either sufficiently large and certain benefits or state pressure to overcome. It suggest there may be a positive feedback between establishing energy management functions and the firm's ability to obtain value from external energy management resources. If true, the developers of energy management tools may have the greatest success in targeting firms with at least a basic comprehension of their internal energy use patterns and the management capabilities to adjust them on the basis of external inputs. However, it is precisely these firms that are likely to have undertaken significant energy-saving investments already. By contrast, firms that are less focused on energy management tend not to be interested in the tool, despite large estimated potential savings. As a result, the firms that are most likely to benefit from the tool may also be the most challenging group to reach.

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Figure A1. A metal press in one of the plants in our sample.

Figure A2. Metal raw materials outside one of the plants in our sample.

Figure A3. Women working on metal lathes in one of the plants in our sample.

Figure A4. Plant workers heading to lunch at one of the plants in our sample.

Table A1. Firm energy management questionnaire.

Practice	Examples of questions we asked	Scoring criteria
Energy Management System	Whether the company has an established energy management system a) Is there an energy management system in your company? b) Has your company met any energy management standards? If so, which standards?	1 point There is no energy management system. 3 points There is an energy management system, but the relevance to any national or international energy management standards is unclear. 5 points There is an energy management system, and the system meets a national or international energy management standard.
Energy Management Capacity	Whether energy managers have professional energy management skills and influence company decisions a) Is there anyone formally appointed as the person in charge of energy? b) Has the person in charge of energy acquired any technical credentials or received any energy management training? c) How does the energy management team influence the company's decision making?	1 point There is no specialized energy management team. 3 points There is a specialized energy management team, but only one person with limited influence on the company's decisions making. 5 points The energy management team is well trained and can influence the company's decisions.
Energy Management responsibilities	Whether energy managers have well-defined formal responsibilities a) Please give a brief introduction to the organization and responsibilities to the energy management team. b) Could you specify the document that defines the above organization and responsibilities, if any?	1 point The energy management team does not have any clearly defined roles. 3 points The energy management team has some responsibilities but they are not clearly defined in a formal document. 5 points The energy management team and personnel have formally defined responsibilities.
Energy Laws and Regulations	Whether employees understand and conform to energy saving laws and regulations a) Please briefly introduce how the company tracks energy saving laws and regulations. b) Please briefly introduce the company's practices to implement these laws and regulations.	1 point The company does not systematically track energy laws and regulations. 3 points The company systematically tracks energy laws and regulations, but the company does not provide the reason for tracking or implementation. 5 points The company systematically tracks the energy laws and regulations. It has a clear goal to implement them, and the goal is aligned with the company's goal.
Energy Monitoring and Review	Whether the company regularly tracks and reviews its energy use a) How often does the company measure and review its energy use? Is there a standardized process? b) Is the firm's energy use compared to any benchmarks? c) Does the company keep a comprehensive record of its energy use and review it regularly?	1 point The company does not review energy use. 3 points The company reviews energy use, but it does not have a clear goal and lacks consistent and quantitative measures of progress. 5 points The review has a clear goal. It is conducted regularly and includes quantitative measures of progress.
Energy Benchmarking	Whether the company has a clear benchmark for measuring energy saving progress a) What standard or approach is applied in to construct benchmark energy use, if any? b) Does the benchmark include energy use at factory, workshop, and equipment level? c) How does the benchmark treat parameters that reflect energy efficiency? d) Under what conditions are the baseline and parameters adjusted? Have they ever been adjusted in the past?	1 point The company does not set an energy benchmark for evaluating progress. 3 points The company has established its benchmark energy use. There is no mechanism for regular adjustment. 5 points The company has an advance energy baseline system. There is a mechanism for regular adjustment.
Energy Targets	Does the firm have energy-saving targets and how are they implemented? a) Are the firm's energy targets documented? b) Is the energy target defined at the level of the company, workshop and equipment? c) Is the company's internal target connected with any external targets or standards? d) What is the process for setting, reviewing, and adjusting energy targets? What happens if the target it met? What happens if the target is not met?	1 point There is no document describing the firm's energy targets. 3 points There is a document that describes the firm's energy targets, but it is not integrated with mandatory requirements and carries no punishment for non-compliance. 5 points Energy targets are well documented, aligned with regulatory requirements, and non-compliance punishments are clearly stipulated.
Information Exchange	How strong is the firm's internal communication around energy saving goals and requirements? a) How is information on the performance of energy-using equipment exchanged among employees? b) Is it common for employees to offer advice or share information on how to improve energy efficiency? Did they receive any reward?	1 point Energy saving knowledge is limited to a small group of employees and not widely understood. 3 points Energy saving knowledge is exchanged internally. Employees occasionally share advice on how to improve energy efficiency. 5 points Energy saving knowledge is frequently shared. Employees are encourage to share advice on ways to improve energy efficiency.
Investment and Procurement	Is energy saving considered in investment, product design, and procurement? a) Is energy saving considered in feasibility studies for new investments or products? Is an energy audit or other measures of energy use required for fixed asset investment projects? b) How does the company analyze energy use and consumption when procuring large energy intensive equipment? Do you calculate life-cycle economic costs? How long is the life cycle or depreciation period considered? c) Please describe how you track and assess energy efficiency during equipment operation and maintenance.	1 point Energy saving is not considered in investment and procurement. 3 points The company considers energy saving in investment and procurement but lacks a systematic assessment approach. 5 points The company considers energy saving in investment and procurement and adopts a systematic assessment approach.
Energy Management Evaluation	How does the company review and improve its internal energy management capabilities? a) How often does the company review its energy management system? What is the objective? Is the board involved? b) How do you correct any problems identified? c) How is performance reviewed? What happens if performance is not satisfactory?	1 point There is no review process, with no rewards or punishments for performance. 3 points There is a review process, but the rewards and punishments are limited or not well defined. 5 points There is a clear review process, and clearly defined rewards and punishments.