

## Industrial Energy Use, Management Practices and Price Signals: The Case of Swedish Process Industry

Anna Dahlqvist<sup>1</sup>, Patrik Söderholm<sup>2\*</sup>

<sup>1</sup>Luleå University of Technology, Economics Unit, 97187 Luleå, Sweden, <sup>2</sup>National Institute of Economic Research, Environmental Economic Research Division, Box 3116, 103 62 Stockholm, Sweden. \*Email: [patrik.soderholm@ltu.se](mailto:patrik.soderholm@ltu.se)

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### ABSTRACT

The objectives of the paper are to: (a) derive and discuss indicators of industrial companies' decision-making and management practices on energy use; and (b) investigate whether these practices can help explain variations in energy intensities across these companies. The data were collected through telephone interviews with 101 large industrial firms in Sweden. The indicators display a significant overall increase in firms' awareness of energy efficiency issues over time, including the attention devoted to these issues at the top management level. Still, our econometric results show that energy prices constitute the most important determinant of inter-firm differences in energy intensities. Higher energy prices over the time-period, have induced the implementation of energy-relevant management and practices, and led to more systematic decision-making processes. Finally, firms for which so-called "hidden" costs, e.g., the costs of production disruptions, are a large concern, will be more energy intense than others.

**Keywords:** Energy Efficiency, Industry, Management Practices, Energy Prices, Sweden

**JEL Classifications:** D22, L23, Q41

### 1. INTRODUCTION

The challenge of climate change in combination with security of supply concerns has spurred an increased societal interest in identifying measures to improve energy efficiency as well as appropriate policies to promote such measures (Lobova et al., 2019; Di Foggia, 2016; Kama and Kaplan, 2013). The industrial sector plays an important role in these policy endeavors; it accounts for about one third of global final energy use and this share has grown over time (e.g., IEA, 2012). Such policy action should however build on an in-depth understanding of energy demand behavior, and on elucidating the potential rationales for policy intervention. Achieving this, though, poses a number of challenges that are both of an empirical and conceptual nature.

First market prices affect firms' decisions on energy use, including investment in more energy-efficient equipment. Such price-induced impacts may often be modest in the short-run due to the

long lifetimes and slow turnover of energy-using appliances and capital equipment. In the long-run, though, energy price changes could have more profound impacts on the adoption of energy efficiency measures as industrial firms have time to replace older capital equipment and develop new processes (Henriksson et al., 2013). Still, existing market-based incentives will not necessarily ensure an economically efficient use of energy. Energy prices may be distorted due to non-internalized environmental costs and/or other market imperfections (Gillingham et al., 2009).

Second, the theoretical rationale for public policy intervention to address energy efficiency is not always straightforward. Different strands of the economics literature - e.g., neoclassical economics, transaction cost economics, behavioral economics, etc. - tend to legitimate a partly varying scope for policy intervention (Sorrell et al., 2004). Neoclassical approaches accentuate empirical evidence on market failures, such as inefficient pricing and information distortions (Brown, 2001; Jaffe and Stavins, 1994;

Gillingham et al., 2009). While this literature stream assumes perfectly rational (i.e., cost-minimizing) firms, the behavioural economics field instead emphasizes the potential bounded rationality of firms. The latter implies that individuals within firms will economize on scarce cognitive resources by utilizing routines and rules of thumb (e.g., Teece et al., 1997; Foss, 2003). This could in turn lead to path-dependent behavior where company executives overlook novel energy efficiency measures (e.g., DeCanio, 1994).

The above points to the importance of addressing both distortions in the energy market, i.e., market failures, as well as decision-making imperfections within energy-using organizations (i.e., behavioral or organizational failures). In this paper, we build on both the neoclassical and the behavioral economics literature to address important market signals as well as firm-specific management and decision-making practices that may explain differences in energy intensities (i.e., the energy required to generate a given output) across firms and over time. Specifically, the objectives of the paper are to: (a) derive and discuss indicators of Swedish industrial firms' decision-making and management practices on energy use; and (b) investigate whether these practices can help explain variations in energy intensities across these firms.

Data on management practices and policies were collected through telephone interviews with 101 industrial process firms in Sweden. The empirical analysis focuses on firms with more than 200 employees in the energy-intensive process industries. In a first step, we document several aspects of firm behavior with relevance to energy use. Since the interviews also involved questions about behavior and practices in the past (i.e., mid-2000s), important changes over time can also be addressed. In a second step, we specify an econometric model in which the energy intensities of 89 firms over the time-period 2004-2010, are assumed to be influenced by the reported management practices as well as by firm output, input use and energy prices.

Sweden is an interesting case study for a number of reasons. In Sweden, energy efficiency is an important policy goal, and the government strives to decrease the country's energy intensity by 20% until the year 2020. The Swedish industrial sectors account for nearly one quarter of total final energy use, and a few energy-intense industries make up nearly three quarters of this total (Swedish Energy Agency, 2018). The latter represent different process industries, such as mining, chemicals, iron and steel, food, and not least the pulp and paper industry. The policy instruments that have promoted a more efficient use of energy in Swedish industry since the turn of the century include energy taxes, investment support and a voluntary energy efficiency program (e.g., Stenqvist and Nilsson, 2012; Henriksson and Söderholm, 2009; Swedish Energy Agency, 2018). Moreover, the price of electricity has increased since 2005 (Brännlund et al., 2012), thus providing an additional spur to economize on energy use.

In the light of the above, this paper contributes to the existing literature in two main ways. First, previous economic studies of factor demand and electricity use in industrial sectors in Sweden and elsewhere primarily address price responses as well as output and productivity impacts (e.g., Adeyemi and Hunt, 2007;

Bjorner et al., 2001; Bjorner and Jensen, 2002; Henriksson et al., 2012; Karimu et al., 2017, Amjadi et al., 2018). In the present paper, though, we devote particular attention to the presence of firm-specific management and decision-making practices. These include the extent to which energy efficiency issues are communicated at the firm level, the priority given to reduced energy use by top management, path-dependent decision-making, and the "hidden" costs of energy efficiency measures in process industries. Second, this paper complements previous research that has used case-based studies to address the different barriers and market failures that may hamper energy efficiency in various sectors (e.g., Schleich, 2009; Sorrell et al., 2004; Rohdin et al., 2007; Thollander and Ottosson, 2008), including studies of existing policies (e.g., Bogoviz et al., 2018; Di Foggia, 2016). Our focus on changes in firm practices over time does contribute to data gathering in this field. Moreover, unlike the above qualitative studies, we combine the collected interview data with secondary industry data, thus permitting explicit quantitative tests of why industrial firms report varying energy intensities. A related approach is employed in Martin et al. (2012) (see also Bloom and van Reenen, 2006), although the former study focuses on climate-friendly management practices in general.

The remainder of the paper is organized as follows. The next section provides a brief discussion of potential market and behavioral failures relating to energy use and efficiency in the industrial sector. Section 3 outlines the design of the interview study, and introduces the various indicators of energy-relevant management practices. In Section 4, we specify the econometric model, and discuss some important data and model estimation issues. The empirical results are presented and briefly discussed in Section 5, while some concluding remarks and implications are outlined in Section 6.

## 2. MARKET AND BEHAVIORAL FAILURES RELEVANT TO ENERGY EFFICIENCY

In this section, we discuss a number of reasons behind the occurrence of a gap between the economically efficient level of industrial energy use and the observed energy use in industry. The analysis in this paper focuses on three categories of explanations for this gap: (a) The non-internalization of external costs; (b) informational inefficiencies; and (c) behavioral failures (e.g., Gillingham et al., 2009; Sorrell et al., 2004)<sup>1</sup>. In addition, we also address a number of additional market barriers to energy efficiency, e.g., overhead costs for energy management, different types of transaction costs, etc. Such so-called "hidden" costs are essential in explaining variations in energy intensities across firms, but they will generally not emerge from market failures and/or behavioral distortions in decision-making, in turn calling for policy intervention.

<sup>1</sup> Additional explanations may include failures in funding new investment, e.g., due to liquidity constraints, and innovation-related market failures that emerge due to the public good nature of new technical knowledge acquired through, for example, R&D investments or learning-by-doing processes (Gillingham et al., 2009).

## 2.1. The Non-internalization of External Costs

Since most energy products are bought and sold in economic markets, industrial actors that use energy have incentives to achieve a more efficient energy use. The role of prices is well founded in both economic theory and in many empirical studies (e.g., Anderson and Newell, 2004; Gillingham et al., 2009; Karimu et al., 2017). Still, the market prices of various energy products and services may not fully reflect the marginal social costs of production (Jaffe and Stavins, 1994). This will be the case if, for instance, different environmental external costs are poorly internalized. In such instances, the energy prices will be too low, and the incentives for energy efficiency investments too weak. Inefficiencies may also arise if the energy generators, e.g., electricity suppliers, apply average cost pricing instead of acting based on prices determined by the marginal costs of production.

In practice, however, it can be difficult to assess the empirical significance of these types of inefficiencies, and thus to define the economically efficient level of energy use. Previous studies that have attempted to assign a value on the environmental cost of electric power generation confirm that this is a difficult task (Sundqvist and Söderholm, 2002). Sorrell et al. (2004) also note that the non-internalization of external costs cannot “explain the neglect of investments, which appear cost-effective at current energy prices,” (p. 30). In other words, inefficient energy use may also stem from factors beyond market prices.

## 2.2. Informational Failures

It is generally not rational for industrial firms to search for and obtain perfect information before making a decision. Hence, the lack of information is not in itself a market failure; in the same way as the purchase of conventional goods is associated with an opportunity cost, searching for new information also commands a price. The mere existence of imperfect information does not therefore justify policy interventions (e.g., Sorrell et al., 2004). However, there are situations in which the presence of incomplete information may lead to an economically inefficient use of energy carriers.

In order to comprehend the underlying informational forces potentially generating inefficient decisions, it is first useful to clarify what types of information that will be relevant. Information pertinent for energy use decisions can be categorized into three groups: Information about: (a) Current use levels in comparison to a benchmark; (b) the different opportunities to save energy given existing conditions (e.g., production processes); and (c) the energy use of new equipment so as to enable a choice between inefficient and efficient options (Sorrell et al., 2004).

The accessibility and quality of information concerning current energy use levels (i.e., category [a] above), depend on, for instance, how well this use is monitored (e.g., the quality of sub-metering), and on whether the appropriate benchmarks are easily accessible. The prevalence of relevant information about relevant energy efficiency opportunities ([b] above), depends on how well these opportunities have been assessed. However, this requires some efforts that will impose costs on the firm (e.g., the cost of

conducting energy audits), whilst the full benefits of obtaining the information will not be known in advance. For this reason, too little information might be supplied (or of too bad quality), or alternatively this type of information might be priced too high. In the case of new equipment ([c] above), the information may also be subjected to the public good problem. If this is the case, the information is likely to be under-supplied due to the opportunity cost of obtaining the information today instead of getting it at a low (or no) cost at a later stage. This gives rise to so-called positive externalities, and an opportunity for some firms to “free ride” on other firms’ adoption of energy efficiency measures. The downside, of course, is that since the firms that choose to invest in new energy efficient technology may not fully reap all benefits of their efforts, most firms will have too few incentives to undertake these investments in the first place.

Besides being under-supplied, information about, for instance, a new technology is also often asymmetrically distributed. The importance of this, Sorrell et al. (2004) argue, depends on the “[...] variance in product quality (particularly in relation to energy efficiency), the frequency of purchase relative to changes in underlying characteristics and the search costs entailed in obtaining relevant information,” (p. 60). Asymmetric information is likely to be more prevalent in the case of energy efficiency opportunities than in, for example, buying an energy commodity such as electricity. The reason for this is that the latter is a homogenous product, which will be purchased on a regular basis, and for which information is widely available. In contrast, energy efficiency investments require the purchase of more complex, heterogeneous and unfamiliar goods for which the lifetime is long, the purchases are infrequent and the rate of technological change is rapid relative to purchase interval (Sorrell et al., 2004).

Akerlof (1970) showed how the presence of asymmetric information could result in so-called adverse selection, e.g., a situation in which primarily energy-intense products are available in the market. Consultants and/or other experts who may have the information advantage, could mitigate this problem by providing convincing information about the economic value of an investment but occasionally, this could also prove difficult in the presence of “invisible” energy efficiency attributes (e.g., Rohdin and Thollander, 2006a; Moberg, 2008). For instance, Brown (2001) provides empirical examples of such market failures preventing the implementation of profitable energy-efficient technologies. For instance, he refers to industry purchasers selecting technology purely based on availability and known dependability of standard equipment.

While Akerlof’s study described inefficiencies that could arise prior to a purchase, the so-called principal-agent problem refers to a situation where asymmetric information distorts incentives after a contract has been signed. Often a distinction can be made between the person who is responsible for the use of energy (such as an engineer in the process industry - the agent) and the manager (the principal) who is responsible for paying the energy bill. Even if the engineer can identify cheap energy efficiency measures, it can be difficult for him or her to convince the manager about the economic benefits of these measures. Alternatively, managers

may be very keen to promote energy efficiency measures, but they nevertheless face difficulties in setting up an organizational structure that provides engineers with the right incentives to meet these goals.

### 2.3. Behavioral Failures

Several studies (e.g., DeCanio, 1998) show that individuals are not always perfectly rational, and they could “neglect opportunities for improving energy efficiency, even when given good information and appropriate incentives,” (Sorrell et al., 2004, p. 10). This is typically referred to as bounded rationality (Simon, 1957; 1979), implying that both firms and households deviate from the behavior of a decision-maker that always makes optimal decisions. Instead, rational behavior will be replaced by the development of imprecise routines and rules of thumb. In industrial firms, this could mean focusing on core activities, such as the primary production process, rather than peripheral issues such as energy use (Sorrell et al., 2004). As a result, some decisions could be allocated to specialists, who replace intangible abstract goals with tangible sub-goals (e.g., Simon, 1979). In line with this, Rohdin and Thollander (2006b) argued that a dedicated energy manager could be an internal force that improves energy efficiency within firms (DeCanio et al., 2000).

In practice, it may be difficult to distinguish behavioral failures from informational ones. For instance, evidence of “lack of dedication” may stem from a split incentives problem. Indeed, split incentives may be strengthened by behavioral failures. In a study on the market for energy efficient electric motors in France, De Almeida (1998) showed that firms chose motors based on reliability and purchase prices, in turn largely neglecting the energy use of the motor. While this was in part due to the fact that maintenance departments were separated from the financial departments (and hence that split incentives could exist), this failure, de Almeida argues, was reinforced due to the development of routines that simplified the decision-making processes at the firm level. These routines are in turn a response to restrictions on time, and the capacity to process information on the part of the maintenance personnel. Such bounded rationality could also influence the effectiveness of policies such as information programs; if agents lack the time or capacity to use existing information, there may be little point in providing more information.

In sum, according to this strand of literature, a set of rules or problem solving techniques within a firm will persist since these existing practices are costly to change but also because the system itself is not questioned. Organizations develop patterns of behavior to respond to problems as they arise, and once a set of rules is developed, it is reinforced by, for instance, in-house training and incentive structures. Hence, bounded rationality often gives rise to path dependent behavior (Heffernan, 2003). In this paper, we investigate the concept of bounded rationality by studying if firms systematically assess all potential energy efficiency measures, or if they simplify their decision-making by choosing between different investment alternatives based on a high degree of implicit or explicit restrictions (e.g., neglecting some types of alternatives by default).

### 2.4. Market Barriers

As was noted above, it is essential to distinguish between market barriers, i.e., conditions that in any way hinder the adoption of energy efficiency measures, and market failures that generate an economically inefficient level of energy use. Costs incurred when evaluating information, choosing between different equipment suppliers, conducting contracts with other actors etc., are all potential barriers to the implementation of energy efficiency measures (e.g., Golove and Eto, 1996). Gillingham et al. (2009) argue that such transaction costs may add to the asymmetric information potentially prevailing between actors, but that acknowledging these types of costs will be necessary in order for productive resources to be efficiently allocated.

The critique of engineering-economic bottom-up models relates partly to its traditional focus on the technological potential of energy efficiency, which however may neglect important costs associated with technology adoption (e.g., Söderholm, 2012). For this reason, these costs are often referred to as “hidden;” they might be accounted for by the firm but they are not accounted for in many engineering-economic models. Table 1 presents a categorization of various hidden costs of energy efficiency investments, including examples of each category. The different types of hidden costs stem from different sources, and are often context- and firm-specific, i.e., they depend on the routines, contractual arrangements, procedures etc., within the firm (Sorrell et al., 2004).

The hidden costs are also likely to vary in importance across different technologies and energy efficiency measures. The costs associated with achieving energy efficiency, such as the cost for production interruptions during the installation of new equipment, are site-specific and hence difficult to generalize. In addition, energy efficiency may be associated with utility or profit losses of an indirect nature. For example, a new motor could be more energy efficient but less reliable. Since energy efficiency seldom is the sole or even the most prioritized attribute of a new technology, these types of “hidden” costs represent real opportunity costs for firms.

In sum, the hidden costs of energy efficiency associated with production (e.g., disruptions) and utility losses (e.g., increases in noise), are inevitable costs where policy typically has a limited role to play. In contrast, the search costs associated with gathering information on, for instance, product quality depend on the markets for information whilst the cost for, say, sub-metering depend on firms’ organizational procedures. Thus, the latter “are contingent upon the relevant market, contractual and organisational structures, and hence may in some circumstances be lowered through public and private actions,” (Sorrell et al., 2004, p. 67).

## 3. FIRM INTERVIEW DESIGN AND VARIABLE DEFINITIONS

### 3.1. Design of Interviews with Industrial Firms

The data on energy-relevant management practices have been drawn from interviews with large industrial firms in Sweden. The study is limited to the energy-intensive process industries, including therefore the following sectors: Mining, food, sawn wood products,

**Table 1: The hidden costs of energy efficiency: Categories and empirical examples**

Categories	Examples
General overhead costs for energy management	Costs of employing specialist staff (i.e., energy managers). Costs of energy information systems (such as the costs for sub-metering, analyzing data and identifying improvements).
Specific costs for a certain energy efficiency measure, such as an technology investment	Costs for “formalities” associated with seeking approval of capital expenditure. Costs of product disruptions and inconveniences. Costs for replacement or retraining of staff.
A possible loss of utility/profit related to a certain energy efficiency measure	Problems with safety, noise, energy service qualities (such as lightning) and working conditions. Lower reliability, additional repairs, etc.

Source: Sorrell *et al.* (2004)

pulp, paper and paperboard, basic chemicals and plastics, iron, steel, foundries and firms producing non-ferrous metals (corresponding to SNI 07, 10, 16, 17, 20 and 24, respectively). We also limited the sample to firms having at least 200 employees. A total of 151 industrial firms fell into this category and were thus contacted. Out of these, 101 chose to participate, thus resulting in a response rate of 67%. The interviews took about 30-45 min to complete, and were directed at the energy managers of each industrial firm.

The interview questions were chosen to address some important management and decision-making practices that may influence firms' energy use patterns. The design of the questionnaire was influenced by the ways in which previous barrier-and-driver studies have been conducted (e.g., Sorrell *et al.*, 2004; Rohdin *et al.*, 2007; Rohdin and Thollander, 2006b; Persson *et al.*, 2005). However, some important differences are worth noting. First, the questions were loosely structured and open, i.e., not meant to simply be answered “yes” or “no”. Following Martin *et al.* (2010; 2012) - and as suggested by Bewley (2002) - the interviewer started by asking an open question about an issue and then followed up with more specific questions and/or asked for some examples of the issues addressed (see section 3.2 for details). This approach provided rich information about the different management and decision-making practices relevant to energy use, and permitted the interviewer to evaluate the answer as accurately as possible.

Moreover, our approach differs from many other survey-based studies since the task of scoring responses (on a five-point scale) was allocated to the interviewer. In this way, one eliminates respondent survey bias, but at the same time, it is important to consider the potential problems of interviewer bias. In the present study, a single interviewer conducted all 101 interviews. Still, eleven interviews were conducted with a second interviewer present, and this person also listed and independently scored the answers (i.e., they were sitting in separate rooms)<sup>2</sup>. This made it possible to test for the possible presence of interviewer bias. Our results show that the scores recorded by the principal interviewer were highly correlated with the scoring of the second interviewer (with the correlation coefficients ranging between 0.8 and 1.0). A comprehensive presentation of the results from this double-scoring test is provided in Appendix A. Finally, in contrast to earlier work, we also attempted to address changes in firms' practices over time. This was done by following up on each question, and asking

the energy manager if the reported management and decision-making practices differed from those in use about 15 years back. In most cases, the respondents were able to answer this question and report examples.

### 3.2. Questions and Variable Definitions

In line with Martin *et al.* (2012), we adopted an ordinal scale of 1-5 to measure management and decision-making practices related to energy efficiency. In order to score each aspect of these practices, a number of general, opened questions were posed while then probing for more details and examples in subsequent questions. The interviewers were in particular gauging the extent to which the firms' practices relevant to energy use are formalized and far-reaching. In the remainder of this section, we introduce and explain the questions posed in the interviews in more detail. The entire questionnaire is available from the authors on request.

One of the topics concerned firms' awareness of energy efficiency issues, and each respondent was asked the following question: “How is the importance of energy efficiency communicated within the firm as a whole?” Respondents were permitted to provide specific examples, and based on the discussion, the interviewer scored the answers according to pre-specified criteria. In the case of firm awareness, the scoring was conducted based on the following criteria:

- Score 1: The importance of energy efficiency is not communicated.
- Score 2: The firm relies solely on informal contacts to communicate the importance of energy efficiency.
- Score 3: The firm arranges occasional training in energy efficiency to staff members.
- Score 4: The firm arranges regular training in energy efficiency to staff members.
- Score 5: The importance of energy efficiency is communicated heavily throughout the firm; it is part of the company culture.

As noted above, this scoring process was then repeated focusing on the situation in the firm going back 12-15 years.

While the question about firm awareness addresses the ways energy efficiency is communicated within the firm as a whole, we also included questions about the extent to which the top management emphasizes the importance of energy efficiency. The following questions were posed: (a) “Is energy efficiency a formal strategic goal in the company?” and (b) “is energy efficiency a (default) topic at top management meetings?” In brief, a score of

<sup>2</sup> Both interviewers had previous experience of conducting research on industrial energy use and barriers to energy efficiency measures.

one (1) represents “no top management awareness” while scores of 2 or 3 imply that these questions are discussed only occasionally at the top management meetings (once or twice per year), and that the top management has informal energy efficiency targets (or guidelines). Scores of 4 or 5 indicate that these questions are discussed continuously, that formal energy efficiency goals exist and that energy efficiency is an important component of the business strategy.

The interviews included a question on whether the firm has hired someone in charge of energy issues (e.g., an energy manager), and (if yes) when this was done. If an energy manager was present, we also asked: “What other responsibilities (if any) does the environmental/energy manager have?” If an energy manager has several other responsibilities (concerning personnel, production, etc.), a low score was set. For instance, a score of 3 is set in the case where he/she had two additional responsibilities, while a score of 5 indicates that energy efficiency issues constituted his/her sole responsibility.

The scope for the energy manager to influence the company’s investment behavior can in turn depend on the organizational structure of the firm. We therefore asked the following question: “How far below the CEO is the energy manager in the corporate hierarchy?” If he/she was more than three levels below the CEO, the score assigned was one (1), <3 but more than one resulted in a score of 3, whilst a score of 5 indicated that the energy manager reports directly to the CEO.

The interviews also covered questions about the extent to which energy audits are conducted at the firm level. If audits are conducted for separate departments, this may create incentives for these departments to keep their energy use down. For this reason, the respondents were asked: “Does the firm audit/monitor the energy use in the production process?” If the firms responded positively to this question, the following questions were added: (a) Describe which types of energy flows that are monitored; (b) describe the system used; (c) how often do you monitor this?; and (d) describe how the energy statistics are then used - what type of analyses are performed? The score was one (1) if no such measures are undertaken, and 2 or 3 if audits are conducted monthly or yearly and if these result in analyses and suggestions for improvements (1-2 times per year). If the energy flows are measured closely, such as by the hour and for every energy source, and if this energy use is reported daily or weekly, in turn leading to continuous analyses and suggestions for improvement, a score of 4 or 5 was provided.

Moreover, the respondents were asked whether the firm has specific energy use goals for the production process, and, if this is the case, to specify how these goals have been formulated. We also asked if “energy efficiency is a criterion when making an investment.” In other words, we were interested in whether the firms had chosen one technology over another based on the former being more energy efficient than the latter. If energy efficiency is never or very rarely considered when making an investment (due to other priorities), the score assigned was one (1) or 2. If the firm applies such a criterion and the respondent could state examples thereof, the score was 3. When the firm’s investment decision

process was based on the use of the “best available technology” (BAT) criterion with respect to energy efficiency - and the respondent could exemplify this - the score was 4 or 5.

The interviews included questions about process integration strategies and priorities, including about efforts to cooperate with, for instance, other industries or district heating networks (e.g., increased utilization of excess heat). This discussion took off with the following question: “Does the firm have any specific strategies aimed at finding economic and energy efficient system solutions?” This was an open question, not scored. The respondent had the ability to describe what strategies were being conducted (if any), as well as the outcome of these.

The last two questions addressed in this section concern the presence of bounded rationality. Few studies have empirically tested different behavioral hypotheses to uncover whether there is a systematic bias in decision-making related to industrial energy use<sup>3</sup>. In the present paper, we operationalize bounded rationality as heuristic decision-making, i.e., wherein firms adopt a sequential decision-making process. This implies that they first narrow their full choice set to a smaller set by eliminating some investment alternatives that do not have some desired feature or aspect (e.g., cost above a certain level, reliability etc.). In a second step, the firms optimize among the smaller choice set, possibly after eliminating further investment options. In the light of this, we asked the following question: “To what extent does the firm systematically assesses all potential energy efficiency measures or is the decision-making process simplified in any way (e.g., through rules of thumb, based on what currently works well, etc.)?” In those cases where the respondent stated that decision-making is simplified, and/or is based on technologies that currently work well, the score given was either 1 or 2. If the respondents exemplified that they make satisfactory, but not optimal considerations, the score was instead 3. Moreover, if the decision-making process appeared less characterized by bounded rationality, i.e., a wide range of options were seriously evaluated and investments were rejected or adopted due to, for example, a rational assessment of risks and rewards, the score given was higher (4 or 5).

Finally, the hidden costs of energy efficiency efforts were investigated by asking the following question: “Are there any other costs, besides those directly related to the investment, that are taken into account when considering a potential energy efficiency investment?” Examples were given to the respondent, e.g., costs of production disruptions, costs of hiring new staff/retraining the existing staff, costs for identifying the efficiency opportunities, analyze their costs, etc. If the respondent could not provide such examples in the context of the firm’s operations, thus illustrating that such costs are considered, the score given was 1 or 2. If such costs prevail, and are occasionally considered, the score was 3. At a score of 4 or 5, the respondent could give specific examples of

3 The existing research focuses primarily on household decision-making (e.g., Hartman et al., 1991; Sanstad and Howarth, 1994; Friedman, 2002; Wilson and Dowlatbadi, 2007). See Broberg and Kazukauskas (2015) for a recent review of research addressing inefficiencies in residential energy use.

the occurrences of such costs, thus implying that an investment in energy efficiency had been considered but not implemented due to the presence of hidden costs.

#### 4. THE ECONOMETRIC MODEL: SPECIFICATION AND ESTIMATION ISSUES

The data collected in the interviews permit us to assess important differences in management and decision-making practices across firms and over time. In this section, we introduce a simple econometric model within which we take the analysis further, and combine the interview data with secondary firm-specific data from Statistics Sweden's industrial statistics. The latter data contain information on the value of output, material and labor expenditures as well as energy prices. The firm-specific energy prices were calculated from the quantities and values reported by firms, and represent the average fuel price based on the two most frequently used fuels in each firm (weighted by use).

This combined approach enables an econometric analysis in which the firm's energy intensity, i.e., the energy use in MWh ( $EU$ ) divided by the value of firm output in kSEK ( $Y$ ), is explained by energy prices, output values, material and labor use, and the different management practices. For our purposes, we apply an unbalanced panel data set covering 89 firms<sup>4</sup> in six Swedish industry sectors over the time period 2004-2010. Hence, we specify the first econometric model (model I) as follows:

$$\ln EU_{it} / Y_{it} = \alpha + \beta_1 \ln Y_{it} + \beta_2 \ln Pave_{it} + \beta_3 \ln Aw_{i(t_1, t_2)} + \beta_4 \ln Rat_{i(t_1, t_2)} + \beta_5 DHC_{i(t_1, t_2)} + \beta_6 \ln L_{it} + \beta_7 \ln M_{it} + \varepsilon_{it} \quad (1)$$

Where the subscript  $i$  represents the firm,  $t$  denotes the years 2004-2010 whilst  $t_1$  and  $t_2$  refers to the two time periods: 2004-2005 and 2010-2011, respectively. The latter is used to denote the fact that the interview data only cover two discrete time-periods.  $Y$  refers to the value of output, while  $L$  and  $M$  denote the values of hired labor and purchased material, respectively. The average price of energy is denoted  $Pave$ . The specification also addresses three important management and decision-making practices, i.e., firm awareness ( $Aw$ ), bounded rationality ( $Rat$ ) and the presence and priority given to hidden costs ( $DHC$ ). Finally,  $\varepsilon_{it}$  is the disturbance term assuming that  $E[\varepsilon_{it}=0]$  and  $\text{Var}[\varepsilon_{it}] = \sigma_\varepsilon^2$ . The logarithmic functional form permits the interpretation of the  $\beta$ -values as elasticities.

Moreover, in an alternative version of the model specification (model II), we also include an interaction variable ( $\ln Aw * DCEO$ ). Here  $DCEO$  refers to the hierarchical distance between the energy manager and the top management<sup>5</sup>. We hypothesize that an increase in firm awareness will have a negative influence on the energy intensity of the firm, and the interaction variable permits us to also

test the hypothesis that a given increase in firm awareness will have a more profound impact on reduced energy use, the shorter is the organizational distance between the energy manager and the top management. In other words, a high firm awareness implies, for instance, that the firms' engineers pay attention to possible energy savings, but these will be hard to implement in practice unless the top management choose to discuss and prioritize these issues. The alternative econometric model - model II - is therefore specified as follows:

$$\ln EU_{it} / Y_{it} = \alpha + \beta_1 \ln Y_{it} + \beta_2 \ln Pave_{it} + \beta_3 \ln Aw_{i(t_1, t_2)} + \beta_4 \ln Rat_{i(t_1, t_2)} + \beta_5 DHC_{i(t_1, t_2)} + \beta_6 \ln L_{it} + \beta_7 \ln M_{it} + \beta_8 (\ln Aw_{i(t_1, t_2)}) * DCEO_{i(t_1, t_2)} + \varepsilon_{it} \quad (2)$$

Table 2 summarizes the definitions and some descriptive statistics for the variables included in the econometric analysis.

Following Baltagi (2008), we apply the Breusch and Pagan's LM (Lagrange Multiplier) statistic test when deciding whether to use the OLS versus the industry-specific effects or random effect models, respectively. We received a test statistic result of 955.95 (933.02 in Model II), while the critical level is 6.63 for chi-squared with one degree of freedom (at the 99% critical level). Based on this, we reject the null hypothesis of no industry-specific effects ( $H_0: F_{\text{ind}} = 0$ ). For this reason, we estimate models I and II using an industry-specific effects method in the LIMDEP software, i.e., setting industry group as the stratifying variable. In this way, we control for the potential unmeasured differences between industries that can be assumed to be fixed over time (e.g., technologies, policy instruments, etc.).

In deciding on an industry-specific effects or a random effects model, Hausman's Chi-squared statistic test help decide between the two. However, such test statistics could not be computed. Greene (2012) then suggests taking the difference between the two estimators to be the random variation. However, when estimating the model, the coefficients turned out to be very similar for the industry-specific and random effects models whilst the industry effects are highly significant in the industry-specific effects model. For the above reason, we focus on the results from the industry-specific effects model<sup>6</sup>.

Finally, we also performed a Hausman test to check for the potential endogeneity problem (e.g., Hill et al., 2008). One may suspect that, most notably, firm awareness and bounded rationality are not exogenously determined variables in the model, this since, for instance, energy intense firms are likely to devote more attention to energy efficiency measures than less energy intense ones. Similar problems would likely be present if, for instance, the occurrence of energy audits were included in the model. For the variables firm awareness and bounded rationality, however, the Hausman test indicated that the null hypothesis of exogeneity could not be rejected. Still, in interpreting the econometric results (Section 5.2), we are careful to refer to our results mainly as

4 Due to lack of data in the industrial statistics, 12 firms had to be removed from the original sample.

5 In Model II, the DCEO variable is coded as a dummy variable that takes the value of one (1) in case of a high score (3-5), and zero (0) otherwise.

6 However, it should be noted that the random effects estimations showed coefficients that were overall very similar to those presented below in the industry-specific effects models. The random effects results are available from the authors on request.

**Table 2: Variable definitions and descriptive statistics\***

Variables	Definitions	Mean±SD	Min	Max
Dependent variable				
Energy intensity (EU/Y)	Energy use (MWh) divided by output (kSEK)	0.180±0.216	0.001	1.651
Independent variables				
Secondary data				
Output (Y)	Gross output (kSEK)	3090350±3936670	125115	25936500
Price of energy (Pave)	Average energy price (kSEK/MWh)	0.442±0.158	0.137	2.191
Material use (M)	Aggregate cost of material (kSEK)	1678470±2277630	16916	19278400
Labor use (L)	Aggregate cost of labor (kSEK)	304730±412032	13604	3482730
Interview data				
Firm awareness (Aw)	Firm awareness of energy efficiency	32.325±13.138	10	50
Interaction variable (Aw*DCEO)	Interaction variable	30.033±15.505	0	50
Rationality (Rat)	Rational decision-making	29.561±13.384	10	50
Hidden costs (DHC)	Dummy that takes the value of 1 in case of a low score (1-2), 0 otherwise	0.242±0.429	0	1

\*In order to facilitate the interpretation of the results, the interview scores have here been scaled up by a factor of 10 (e.g., from 1 to 10, 2 to 20, etc.). Moreover, one (1) USD corresponds to about 8 SEK

statistical correlations, thus not providing explicit information about the causal directions.

## 5. EMPIRICAL RESULTS

In this section, we present the empirical results. Section 5.1 presents some descriptive results from the interviews, highlighting in particular the different energy-relevant management and decision-making practices at the firm level. In section 5.2, we outline and discuss the results from the econometric models addressing the extent to which observed differences in energy intensities across the firms can be explained by, most notably, energy prices and the different management practices.

### 5.1. Management Practices and Barriers to Energy Efficiency

Figure 1 shows the average scores of different potential barriers and management practices in the 101 firms interviewed. It also displays changes over (roughly) the most recent 15-year period. The results illustrate that energy efficiency issues tend to be well-communicated within the firms, and the top managements devote quite a lot of attention to these issues (at meetings, etc.). In most of the firms, the employees obtain information and education relating to energy efficiency opportunities, although the magnitude and the frequency of these activities differ across firms (Table 2). Information on energy use is provided through, for instance, intra networks, monthly or weekly reports, and/or at regular meetings. Some firms also have special energy groups responsible for disseminating such information to the regular staff. Others have launched special “employee energy efficiency campaigns.”

Top managers tend to view energy efficiency as a strategic goal discussed regularly. The reason for this, as expressed by one respondent, is that “the top managers got very aware when they saw the economic significance of future energy savings.” Another respondent stressed that “the awareness has increased due to increasing energy costs - it makes logical sense to be more aware.” The respondents also emphasized that the process industry has devoted a lot of attention to energy efficiency measures already in the past due to high energy costs. Awareness was, according to one respondent, high during the oil crises in the 1970s; throughout

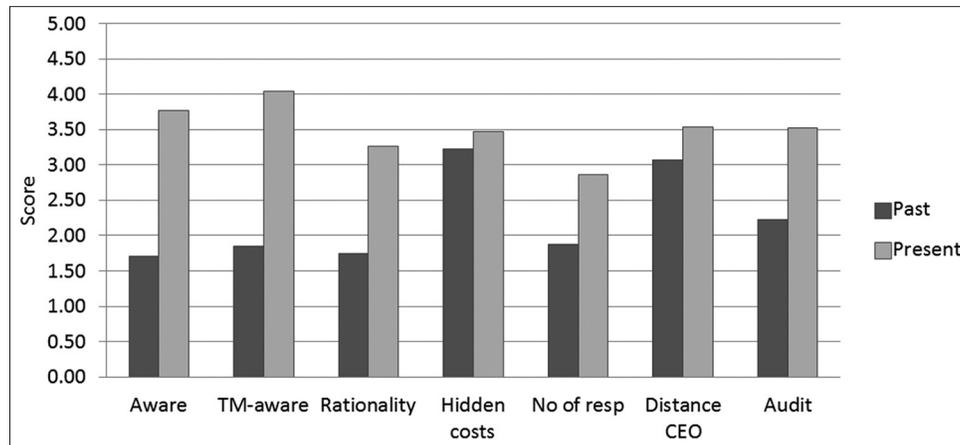
this period the industry “hunted savings,” but in the early 2000s, energy was so cheap that it was considered less important to invest in awareness-raising investments. This notion is reflected in Figure 1, showing a significant increase in firm awareness during the second half of the 2000s, this due to both higher energy prices and a stronger focus on climate change.

Figure 1 shows that there is some evidence of bounded rationality on the part of firms, although overall at the present, our sample firms work systematically with energy efficiency issues and appear thus to seriously consider - and assess - a wide range of energy solutions. In this process, as one respondent puts it, “the only rational is to reject new equipment that is not commercially viable.” According to some of the respondents, their firms have always worked systematically but nevertheless quite often with a different focus. In the past, “it was more about quality.” Investments were done to increase productivity, i.e., they had a focus on product quality and energy efficiency could often be of secondary importance. This is also consistent with the scores reported in Figure 1, showing that firms pay more attention to assessing all potential energy efficiency measures than was the case during the early 2000s. Other respondents in the survey emphasized that for their firm, product quality is still the main priority (together with production process reliability), and that their processes require high energy use levels to maintain high quality. Some firms stressed that they invest in “what is known to work.” Still, in many firms the trend is towards a more systematic way of assessing different energy solutions, not the least since this is economically motivated in the light of higher energy prices.

The hidden costs of energy efficiency investments are overall considered important to address, and this was the case even during the mid-2000s (i.e., no significant difference between the past and the present)<sup>7</sup>. Many of the respondents emphasized that in process industries unplanned production disruptions should not happen; if an investment project risks disrupting production, it will typically be rejected. This implies that hidden costs may

<sup>7</sup> Some respondents noted, though, that when energy was relatively cheap in the past, production equipment was often oversized to have the capacity to deal with temporary production peaks even though this led to unnecessarily high energy use during normal operations.

**Figure 1:** Management practices and barriers to energy efficiency (average scores). “Aware” and “TM-aware” are abbreviations for firm and top management awareness, respectively



represent significant barriers to energy efficiency measures in the process industry. Nevertheless, some respondents' stated that their suppliers may bear some of these costs since they - besides supplying new equipment - also have to provide the related educational services.

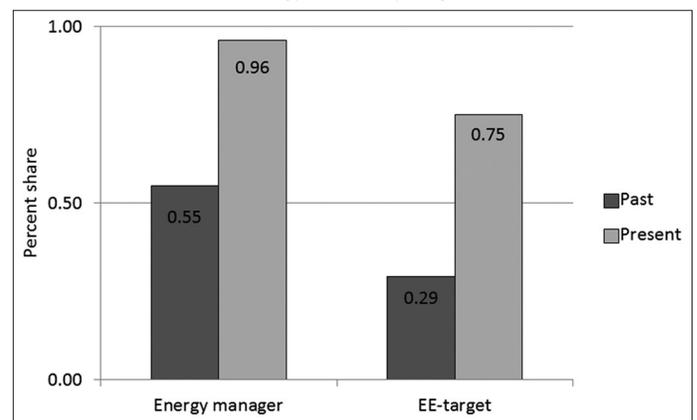
In Figure 1, “No of resp.” is short for the number of responsibilities, besides energy issues, that an energy manager could have. Here, the increase in the reported score over time implies that energy managers in general now have fewer responsibilities compared to the situation in the mid-2000s. The average present score is 2.9 while it was 1.9 in the past. This thus permits energy managers to devote more attention to energy efficiency issues. Moreover, Figure 1 also shows that the hierarchical distance between the energy manager and the CEO (measured in corporate levels) has decreased over the period, i.e., the corresponding score has increased to 3.5. This means that the energy managers work (and report) closer to the CEO today compared to the situation in mid-2000s. The relevance of this for pursuing energy efficiency measures may be influenced by other factors as well. For instance, one respondent argued that due to a shift in the ownership structure, he could more easily “reach through” when presenting a “rational energy efficiency investment” that previously would have been rejected by the top management.

Finally, according to Figure 1, energy audits are more thoroughly conducted today than was the case in the mid-2000s. This implies, for instance, that the methods used are more sophisticated, the audits are done more frequently, and the results from these are followed up more closely. Some of the respondents stressed that their measurement techniques have remained the same since the early 2000s, but today the results from these are followed up more frequently and are also better communicated throughout the entire organization<sup>8</sup>.

The attention that industrial firms pay to energy efficiency activities can also be measured by assessing whether the firms have

<sup>8</sup> The question posed in the interviews dealt with energy audits conducted in the production process. A majority of the respondents described their audits with a production process focus, while a few also described their audits on a more general basis.

**Figure 2:** Share of firms with an appointed energy manager and an energy efficiency target



an appointed energy manager or not, and/or whether they have formulated explicit energy efficiency targets for their production processes. Figure 2 shows the share of firms having an energy manager and an energy efficiency target, respectively. Almost all firms in our sample have a specially appointed energy manager, and this share has increased significantly since the mid-2000s. The energy manager disseminates information, and in some firms this person arranges monthly meetings with the heads of the different departments. In addition, in recent years most of the firms (75%) also have an explicit energy target for their production process. These targets are often expressed quantitatively, e.g., in terms of the maximum use of energy per produced unit of output. A few respondents also expressed that their firms' focus on energy efficiency is often reflected in their marketing activities. Energy efficiency signaling - also a concern for environmental issues in general - is thus here viewed as contributing to a competitive advantage in the market place.

Industrial firms devote attention to energy use not only by considering whether or not to invest in explicit energy efficiency measures. All investments typically have energy use implications, and for this reason the respondents were asked if energy efficiency is one of the criteria when making a new investment. Figure 3 illustrates the frequency of scores for this question, and it shows

that 38% of the respondents state that their firms choose between investments using the - from an energy use perspective - BAT criterion.

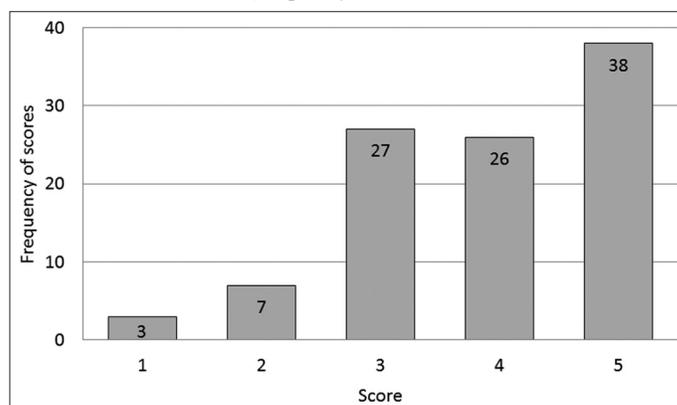
Many energy efficiency investments represent improvements carried out in various auxiliary systems, i.e., pump systems, electric motors, ventilation, etc. These investments generally have pay-off periods shorter than 3 years. Some respondents discussed the applied discount rates used, and these tend to range between 7 and 20%. However, some mention that they may consider longer pay off periods (i.e., lower rate-of-return requirements) as well “if the project is good.” Despite this, though, “high risks” and “insufficient internal funding” are frequently mentioned as important obstacles to the adoption of energy efficiency measures. Hence, we can conclude that BAT is applied when energy efficiency is prioritized in the first place. Other investments with longer pay back periods may have other priorities, e.g., quality or production reliability. One respondent expressed this in the following way: “Energy efficiency has a lower priority than technologies we know work better.”

Figure 4 illustrates the most frequently mentioned sources of information when learning about different energy efficiency measures. A majority of the respondents state that their firms rely heavily on information provided by the firms’ employees as well as by equipment suppliers (90% and 84%, respectively). Consultants and universities also represent important information sources. Some firms (42%) noted that they have research and development groups, which typically adopt a “broader system perspective.” In addition to the sources given in Figure 4, some respondents also mentioned the importance of industry magazines, seminars and workshops. Firms, some argued, often benefit from knowledge spillovers from other’s experiences, not least “good examples” in the same industry. Others stressed that they also try to learn from other industrial sectors.

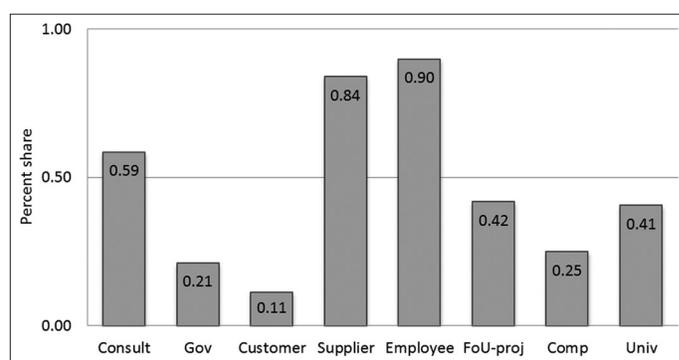
Finally, the respondents had the opportunity to describe important energy efficiency measures undertaken that build on a broader system perspective, i.e., process integration activities and cooperation with other industries and energy sectors (e.g., making use of excess heat). Most firms appear to have no formalized way of working thoroughly with such systems perspectives. The respondents stated that they try to incorporate a systems perspective, but they were seldom explicit about the ways in which this was realized. A few respondents stressed that their own firms have considered, but many have not (yet) implemented, measures that could increase the utilization of excess heat (e.g., by supplying it to a district heating network). Others address the importance of “thinking in a longer perspective”, and this is typically realized through life cycle cost analyses when considering energy-intensive investments. A few respondents mentioned that they have conducted Pinch analysis<sup>9</sup>, and stressed the importance of industry-wide teams within which the sharing of cross-sector knowledge can take place.

<sup>9</sup> Pinch analysis provides tools that permit one to investigate the energy flows within a process, and to identify the most economical ways of maximizing heat recovery and/or of minimizing the demand from external utilities (e.g., steam and cooling water etc.).

**Figure 3:** Weight given to energy efficiency in investment decisions (frequency of scores)



**Figure 4:** Sources of information in learning about energy efficiency measures



## 5.2. Results from the Econometric Analysis

The previous section showed that overall, our sample firms devote a lot of attention to energy efficiency, and there is clear evidence that these issues have been given more and more weight over time. However, we also find important differences across firms, and in this section, we investigate the extent to which differences in awareness and energy-decision processes can explain the observed energy intensities (i.e., energy use in MWh by output in kSEK) in 89 firms over the time-period 2004-2010. Table 3 displays the parameter estimates for the two model specifications introduced above (with *t*-values adjusted for heteroskedasticity). The  $R^2$ -adjusted values are 0.480 and 0.479, respectively, for the two models, thus indicating relatively good fits (at least considering the strong cross-sectional nature of the panel data set).

The model specifications include a number of control variables such as the values of firm output as well as labor and material expenditures. The empirical results show that large firms tend to be more energy intense than the ones with lower firm output values. Moreover, firms with high aggregate material expenditures typically have relatively low energy intensities. However, the coefficient representing total labor expenditures is not statistically significant. Since the fixed industry group effects are statistically significant, we can conclude that industry heterogeneity matters. The different industries differ not least in terms of production technologies requiring varying amounts of energy.

**Table 2: Variable definitions and descriptive statistics\***

Variables	Definitions	Mean±SD	Min	Max
Dependent variable				
Energy intensity (EU/Y)	Energy use (MWh) divided by output (kSEK)	0.180±0.216	0.001	1.651
Independent variables				
Secondary data				
Output (Y)	Gross output (kSEK)	3090350±3936670	125115	25936500
Price of energy (Pave)	Average energy price (kSEK/MWh)	0.442±0.158	0.137	2.191
Material use (M)	Aggregate cost of material (kSEK)	1678470±2277630	16916	19278400
Labor use (L)	Aggregate cost of labor (kSEK)	304730±412032	13604	3482730
Interview data				
Firm awareness (Aw)	Firm awareness of energy efficiency	32.325±13.138	10	50
Interaction variable (Aw*DCEO)	Interaction variable	30.033±15.505	0	50
Rationality (Rat)	Rational decision-making	29.561±13.384	10	50
Hidden costs (DHC)	Dummy that takes the value of 1 in case of a low score (1-2), 0 otherwise	0.242±0.429	0	1

\*In order to facilitate the interpretation of the results, the interview scores have here been scaled up by a factor of 10 (e.g., from 1 to 10, 2 to 20, etc.). Moreover, one (1) USD corresponds to about 8 SEK

**Table 3: Parameter estimates from the industry group effects models**

Independent variables	Model I		Model II	
	Coefficients	t-ratios	Coefficients	t-ratios
Output (LnY)	***0.359	3.648	***0.352	3.566
Average energy price (LnPave)	***-1.196	-8.746	***-1.216	-8.762
Material (LnM)	***-0.314	-3.930	***-0.311	-3.894
Labor (LnL)	0.115	1.317	0.125	1.429
Firm awareness (LnAw)	0.151	1.440	0.108	0.977
Interaction variable ((LnAw)*DCEO)	-	-	0.049	1.170
Bounded rationality (LnRat)	0.139	1.394	0.127	1.265
Hidden costs (DHC)	***0.363	3.858	***0.356	3.780
Industry groups	Estimated industry group effects		Estimated industry group effects	
	Coefficient	t-ratios	Coefficient	t-ratios
1	***-7.219	-10.343	***-7.233	-10.382
2	***-7.082	-11.752	***-7.129	-11.860
3	***-7.039	-11.628	***-7.111	-11.760
4	***-5.862	-9.477	***-5.936	-9.609
5	***-7.436	-12.391	***-7.506	-12.525
6	***-6.917	-11.198	***-6.970	-11.311
	R <sup>2</sup> -adjusted=0.480 Breusch and Pagan's LM test statistic=955.95		R <sup>2</sup> -adjusted=0.480 Breusch and Pagan's LM test statistic=900.27	

\*\*\*Indicates statistical significance at the 1% level

An important result from the model estimations is that the average price paid for energy is strongly and negatively correlated with the energy intensity. For instance, a price increase by one (1) % suggests a 1.2% decrease in energy intensity. Given the strong cross-sectional nature of the data set (including 89 firms), this result is probably best interpreted as a long-run price response. This result is consistent with the notion that energy-intensive process industrial firms devote a lot of attention to rising energy costs, and are willing to take means to reduce these. Nevertheless, energy efficiency measures come at a cost. Our results also suggest that firms that identify significant hidden costs associated with energy efficiency measures, and that take these into account in their decision-making, also have higher energy intensities. This positive correlation between hidden costs and energy intensity is highly statistically significant. Clearly, the presence of - and the concern for - various hidden costs implies that some energy efficiency measures will be rejected.

The empirical results also indicate that there is no statistically significant correlation between the level of awareness, i.e., where

energy efficiency issues are effectively communicated to the entire organization, and observed energy intensities. Statistically insignificant correlations were obtained when including top management awareness in the models. In addition, the interaction variable, i.e., testing whether an increase in firm awareness will be less correlated with energy intensity if there is a significant distance between the energy manager and the top management, was also found to be statistically insignificant.

Hence, in our empirical context, differences in firm awareness across firms do not appear to shed light on why some firms are more energy intense than others. One reason for this result may be that our sample only contains energy-intensive process industries, and these are overall more attentive to energy use issues than, say, small- and medium-sized, and less energy intense firms. In other words, although differences in awareness exist across the firms in our sample, these may not be big enough to matter for energy use outcomes. Furthermore, awareness of energy efficiency opportunities is likely not independent of energy price levels, thus suggesting that firm

and top management awareness may well be embedded in the price responses reported above.

Finally, the results in Table 3 suggest that firms that systematically evaluate different energy efficiency measures do not (*ceteris paribus*) appear to have lower energy intensities than those who show stronger evidence of heuristic decision-making (e.g., rules-of-thumb, etc.). Hence, while Table 2 shows that there exist differences across firms in terms of bounded rationality, Table 3 suggests that these cannot shed light on the diverging energy intensities across firms. One possible interpretation of this result is that although some firms apply more restrictive decision-making practices, these are nevertheless more or less optimal from the perspective of the objectives of the firm. In other words, the restrictions imposed on the decision-making process, may not be “binding,” and the firms practicing these appear not to be missing out on highly profitable energy efficiency measures. Moreover, as also noted above, the presence of systematic decision-making in the energy field is likely to be correlated with the level of energy prices.

## 6. CONCLUDING REMARKS

In this paper, we have identified a number of key barriers and drivers to energy efficiency in Swedish process industry. The descriptive results show that the awareness of energy efficiency within firms has increased over time since the mid-2000s. In addition, top managers also devote a more attention to energy efficiency issues compared to earlier time-periods. The respondents argued that this increased awareness is mainly due to rising energy costs. Nevertheless, the econometric model estimations showed that firm awareness does not appear to be correlated with the energy intensity. Instead, rising energy prices will significantly reduce the energy intensity. Hence, in line with economic theory and previous studies, our paper shows that the energy price is an external driver forcing firms to economize on their energy use. Firms seek to maximize profits, and hence have incentives to reduce energy costs and achieve a more efficient use of energy. Firm awareness is also likely to be positively correlated with high energy prices.

Firms are also more systematically evaluating different energy efficiency measures than has been the case in the past. Still, the quantitative results show that this change in behavior (i.e., increased rationality) appear to have had modest effects on the level of the energy intensity. Thus, even though firms apply rules-of-thumb in their decision-making, one could consider this behavior as “sufficiently” rational from an economic efficiency perspective. Close to 40% of the firms choose between investments using the BAT criterion. Still, many of the investments represent energy efficiency improvements carried out in various auxiliary systems such as pump systems, electric motors and ventilation systems. These investments typically have payback periods that are shorter than 3 years. Hence, we can only conclude that BAT is applied when energy efficiency is prioritized in the first place. Other investments (e.g., with longer payback periods) may often involve other priorities, such as quality concerns and production reliability.

Both the descriptive results and the model estimations show that hidden costs may constitute important barriers to lower energy intensities. In firms for which such costs are a large concern, the energy intensity levels are generally higher. Hence, when these costs are considered, energy efficiency investments may be rejected frequently. Nevertheless, when learning about an energy efficiency investment, over 80% of the respondents point out equipment suppliers as an important “informational source”. In this respect, respondents argue that their suppliers provide education on, for instance, new equipment as a service when supplying a product. Hence, this could decrease the potential problems of asymmetric information that any hidden costs may reinforce.

## 7. ACKNOWLEDGMENTS

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## APPENDIX

### Appendix A: Testing for the Presence of Potential Interviewer Bias

In this paper, the data collection procedure differs from other survey studies since the task of scoring responses was allocated to the interviewer. We thereby eliminate respondent survey bias, and instead we have to consider potential problems of interviewer bias. In the study, a single interviewer conducted all interviews (a total of 101). In addition, 11 of the telephone interviews were conducted with a second interviewer present in another room; she also listed and independently scored the answers. Figure A1 reports the average firm score by interviewer 1 in relation to the average firm score by interviewer 2. The plot in Figure A1 shows a strong positive relationship between the scoring of interviewer 1 and interviewer 2.

Figure A1: Average score per firm and interviewer

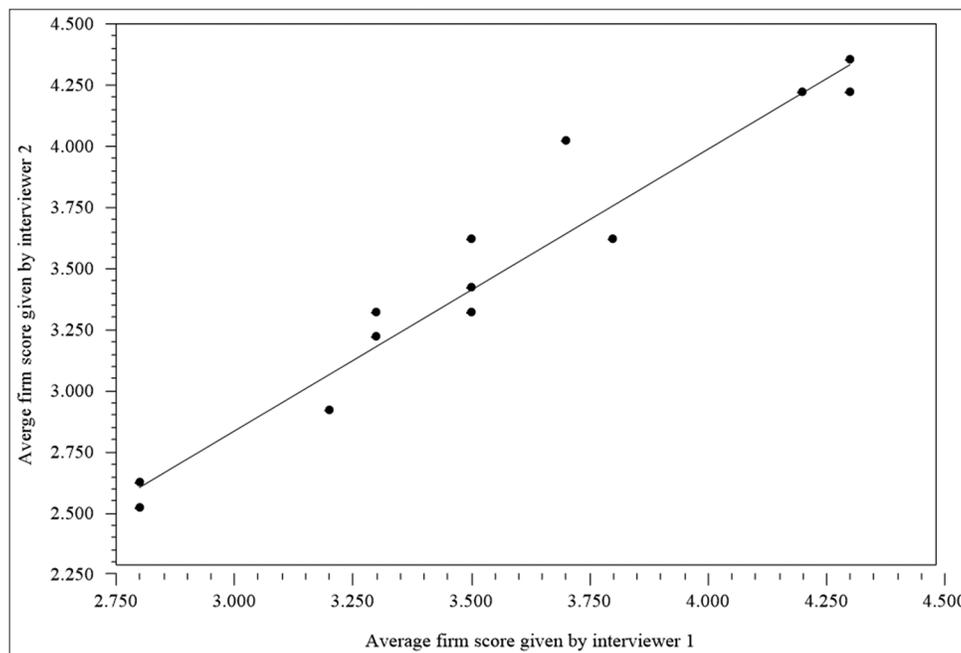


Table A1 presents the “per question-results” of the double scoring as well as the correlation between the two scores recorded. The correlations between the scores range between 0.78 and 1.00, thus suggesting that the interviewer bias is very limited. In Table A1, the abbreviations “I1S” and “I2S” denote “Interviewer 1 Score” and “Interviewer 2 Score”, while “Q” is short for question<sup>1</sup>. The correlation 1.00 for the questions 7-10 deserves a comment. These questions are relatively straightforward; questions 7 and 8 concern the number of other responsibilities (“several,” “two” or “no other”) pertained by the energy manager, while questions 9 and 10 concern the distance (“more than 3,” “2-3”, or “1”) between the CEO and the energy manager. Hence, the relative ease of scoring these questions, although requiring some amount of judgment, in part explains the correlation of 1.00 between interviewer 1 and interviewer 2 scores.

Table A1 demonstrates that the double-scored firms differ slightly from the total sample. On average they have high top management awareness of energy efficiency issues, and has energy managers with few other responsibilities that work <2 levels below the CEO. The average firm conducts audits and analyses on a production process basis, has energy efficiency as a criteria when making investments, acts rational in some occasions, while not in others, and finally, the average double scored firm often accounts for all costs, hence also the “hidden” ones - whereby the latter may result in some energy efficiency investments not being realized.

<sup>1</sup> Table A1 does not contain all questions due to either missing observations or as a result of the design of the questions (e.g., yes/no questions).

**Table A1: Double scoring results by question**

<b>Q1: Firm sawareness</b>		<b>I1S</b>	<b>I2S</b>	<b>Q3: Top management awareness</b>		<b>I1S</b>	<b>I2S</b>
Firm 1		2	3	Firm 1		5	4
Firm 2		1	1	Firm 2		3	4
Firm 3		3	3	Firm 3		2	3
Firm 4		3	3	Firm 4		2	2
Firm 5		4	4	Firm 5		4	5
Firm 6		3	3	Firm 6		3	4
Firm 7		4	4	Firm 7		4	4
Firm 8		4	3	Firm 8		5	5
Firm 9		5	5	Firm 9		5	5
Firm 10		1	2	Firm 10		3	3
Firm 11		3	4	Firm 11		5	5
Mean		3.00	3.18	Mean		3.73	4.00
Correlation: 0.88				Correlation: 0.84			
<b>Q7: No. responsibilities - today</b>		<b>I1S</b>	<b>I2S</b>	<b>Q8: No. Responsibilities - previously</b>		<b>I1S</b>	<b>I2S</b>
Firm 1		5	5	Firm 1		3	3
Firm 2		3	3	Firm 2		3	3
Firm 3		5	5	Firm 3		3	3
Firm 4		5	5	Firm 4		5	5
Firm 5		5	5	Firm 5		3	3
Firm 6		5	5	Firm 6		5	5
Firm 7		1	1	Firm 7		1	1
Firm 8		5	5	Firm 8		1	1
Firm 9		1	1	Firm 9		1	1
Firm 10		3	3	Firm 10		3	3
Firm 11		3	3	Firm 11		3	3
Mean		3.73	3.73	Mean		2.82	2.82
Correlation: 1.00				Correlation: 1.00			
<b>Q9: Distance to CEO - today</b>		<b>I1S</b>	<b>I2S</b>	<b>Q10: Distance to CEO - previously</b>		<b>I1S</b>	<b>I2S</b>
Firm 1		3	3	Firm 1		3	3
Firm 2		3	3	Firm 2		5	5
Firm 3		5	5	Firm 3		3	3
Firm 4		5	5	Firm 4		3	3
Firm 5		3	3	Firm 5		1	1
Firm 6		5	5	Firm 6		5	5
Firm 7		5	5	Firm 7		5	5
Firm 8		3	3	Firm 8		5	5
Firm 9		3	3	Firm 9		3	3
Firm 10		3	3	Firm 10		1	1
Firm 11		3	3	Firm 11		5	5
Mean		3.73	3.73	Mean		3.55	3.55
Correlation: 1.00				Correlation: 1.00			
<b>Q11: Audit/analysis</b>		<b>I1S</b>	<b>I2S</b>	<b>Q15: EE as an investment criteria</b>		<b>I1S</b>	<b>I2S</b>
Firm 1		5	5	Firm 1		3	3
Firm 2		2	3	Firm 2		3	3
Firm 3		3	3	Firm 3		3	3
Firm 4		3	3	Firm 4		4	4
Firm 5		4	4	Firm 5		4	5
Firm 6		5	5	Firm 6		4	5
Firm 7		3	3	Firm 7		4	4
Firm 8		5	4	Firm 8		5	4
Firm 9		2	3	Firm 9		2	3
Firm 10		3	3	Firm 10		2	3
Firm 11		5	5	Firm 11		5	5
Mean		3.64	3.73	Mean		3.55	3.82
Correlation: 0.91				Correlation: 0.78			
<b>Q24: Rationality</b>		<b>I1S</b>	<b>I2S</b>	<b>Q28: Hidden costs</b>		<b>I1S</b>	<b>I2S</b>
Firm 1		3	4	Firm 1		1	2
Firm 2		2	3	Firm 2		4	4
Firm 3		3	3	Firm 3		3	2
Firm 4		2	3	Firm 4		2	2
Firm 5		5	5	Firm 5		3	3
Firm 6		4	3	Firm 6		3	2
Firm 7		5	4	Firm 7		4	4
Firm 8		2	3	Firm 8		5	4
Firm 9		5	4	Firm 9		5	5

(Contd...)

**Table A1: (Continued)**

<b>Q24: Rationality</b>	<b>I1S</b>	<b>I2S</b>	<b>Q28: Hidden costs</b>	<b>I1S</b>	<b>I2S</b>
Firm 10	2	2	Firm 10	4	5
Firm 11	5	5	Firm 11	5	5
Mean	3.46	3.55	Mean	3.55	3.46
Correlation: 0.80			Correlation: 0.85		

The answers were graded on a scale from one (1) to 5. Q1 and Q3: High score=high awareness, Q7 and Q8: High score=few other responsibilities, Q8 and Q9: High score=few organizational levels between energy manager and CEO, Q11: High score=thorough audits/analyzes are pertained, Q15: High score=energy efficiency is an important investment criteria, Q24: High score=rational behavior, Q28: High score=hidden costs are considered and act as a barrier