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The relationship between enterprize efficiency in resource use and energy efficiency practices adoption

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ABSTRACT

The purpose of this paper is to investigate the relationship between enterprize efficiency in resource use and the adoption of energy efficiency practices recommended by the US Department of Energy (DOE) through the Industrial Assessment Center (IAC). Using non-parametric techniques such as Data Envelopment Analysis (DEA) and parametric techniques like Stochastic Frontier Analysis (SFA) and Corrected Ordinary Least Square (COLS) to measure the efficiency. The Regression Quantile (RQ) is carried out to test the hypothesis that the most efficient companies have adopted a higher level of practice. The main conclusion is that when the enterprize operates at increasing Returns-to-Scale (RTS) the impact of efficiency on adoption increases positively, inversely when the enterprize operates at decreasing (RTS) the impact of efficiency on adoption increases negatively.

1. Introduction

The study of energy efficiency is not a new area; it is the focus of the studies that has changed, it went from energy conservation (Motamen and McGee, 1986; Fawkes and Jacques, 1987) to energy efficiency (Phylipsen, et al., 1997; Worrell et al., 2003), to the impact of energy use on sustainability (Gutowski et al., 2005; DelRio and Burguillo, 2008) and energy management (Bunse et al., 2011; Backlund et al., 2012; Negai et al., 2013). The studies have identified various benefits of energy efficiency management in companies: Increased productivity, reduced pollution, reduced noise, low cost of maintenance, savings in water, reduced waste, among other benefits (Worrell et al., 2003; Trianni et al., 2014). On the other hand, the studies have also identified what is known in the literature as the *Energy Efficiency Gap*, the paradox of the existence of this gap is explained by a series of barriers that prevent greater efficiency (Jaffe and Stavins, 1994; DeCanio, 1998; Cagno, et al., 2013). This gap exists as a result of not implementing energy efficiency or energy conservation measures even though their cost effectiveness has been evaluated by techniques like *payback*, internal return rate (IRR) or net present value (NPV) (Jaffe and Stavins, 1994; DeCanio, 1998).

In the analysis of three bibliometric studies: Yaoyang and Boeing (2013), Du et al. (2013), and Du et al. (2014) comparing more robustly the total number of publications and citations in the periods 1993–2001 to 2002–2010, results show a growing interest in some specific areas in the field of energy. In the area of biofuels, as showed by Yaoyang and Boeing (2013), there was a 1310% increase in publications and 1946% in the number of citations, in the area of energy efficiency, according to Du et al. (2013), a 278% and 396% increase, and finally in solar energy, as showed by Du et al. (2014), an increase of 103% and 187% for the same indicators. Based on these studies there is a greater relative interest in researching energy efficiency over solar energy.

Data sources for energy efficiency research are scarce. One study opportunity comes from the Department of Energy of the United States (DOE), through the energy efficiency audit program for small and medium enterprizes (*SMEs*), sponsored by the American government (US DOE-IAC, 2011). Participating in the study are 24 *Industrial Assessment Centers* (IAC) together with 32 American universities.

Many studies have used the information provided by the DOE-IAC for investigating impacts such as cost, price of energy, time of return on investment and other factors, on the implementation of energy management and energy efficiency practices (Tonn and Martin, 2000; Anderson and Newell, 2004; Abadie et al., 2012;

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Therkelsen and McKane, 2013; Blass et al., 2014). The main contribution of our work is to look at how prior enterprize efficiency has had an influence on the adoption of practices, in other words: What is the relationship between enterprize efficiency and the adoption of energy efficiency practices? The efficiency is measured by three different techniques: Data Envelopment Analysis (DEA), Stochastic Frontier Analysis (SFA) and Corrected Ordinary Least Square (COLS). DEA, SFA and COLS provide methods for estimating the best practice production frontiers and evaluating the relative efficiency of different entities (enterprize). The efficiency is measured by the distance between the enterprizes that are on the frontier and below it (Bogetoft and Otto, 2010). The Regression Quantile (RQ) is carried out to test the hypothesis that the most efficient companies, measured by DEA, SFA and COLS, have adopted a higher level of practice. A second question is raised: Considering the practices, is there a difference in efficiency among the enterprizes that adopted certain practices and those that did not?

The idea behind the first question is to generate evidence demonstrating that the most efficient companies are also those more concerned with environmental issues, since the use of less energy results in fewer harmful gas emissions into the environment (CO_2, CH_4, N_20). The second question seeks to determine whether or not more efficient companies have a preference for any particular practices.

This study uses the model proposed in Perroni et al. (2015), including the year 2013 in the model. A specific set of objectives was used to deal with the large body of information, approximately 17,000 cases and 130,000 recommendations, broken down into the following sections: literature review of the determinants of energy efficiency; research design, which describes the treatment of data, construction of models for calculating the efficiency, model to examine the research question, and application and test methodology; calculations of efficiency and the model which investigated the relationship between the enterprize efficiency and the adoption of energy efficiency practices; and at the last two sections discussion and conclusion are presented.

2. Literature review of the determinants of energy efficiency

Enterprize efficiency can be analyzed in various ways, the most widely known are technical efficiency and allocative efficiency. Technical efficiency is related to the use of adequate or optimal procedures and allocative efficiency takes into consideration the costs of these procedures for optimal allocation (Farrel 1957; Bogetoft and Otto, 2010).

According to Patterson (1996) efficiency in the context of energy is a generic term, where there is no single measure. Efficiency is related to the use of less input (energy), maintaining a constant output. For Patterson (1996) the energy efficiency indicator comes from the output/input ratio, classified in four groups: *Thermodynamic, Physical-thermodynamic, Economic-thermodynamic, Economic.*

The link between the concept of energy efficiency and energy management can be interpreted according to the definition put forth by Bunse et al. (2011, p. 668) "*In our research we define 'energy management in production' as including control, monitoring, and improvement activities for energy efficiency*". Based on the research of Backlund et al. (2012) both the policy documents and the academic literature recognize the existence of the so-called *energy efficiency gap*, which is related to the non-implementation of measures for energy management and energy efficiency, despite their cost effectiveness.

Studies evaluating the extent to which energy management has been adopted by industrial companies have revealed a low rate of adoption. For 304 industrial companies in Denmark, Christoffersen et al. (2006) concluded that between 3% and 14% of the companies practiced energy management. In analyzing intensive Swiss industries like paper and foundry Thollander and Ottosson, 2010 found that 40% and 25% respectively, practiced energy management. Studies in Italy found that in small and medium-sized companies the *energy efficiency gap* can be explained by a series of barriers such as: *High investment costs, hidden costs, intervention not sufficiently profitable, information issues on energy contracts, information not clear by technology suppliers and lack of information on costs and benefits* (Trianni and Cagno, 2012; Trianni et al., 2013).

Concerns over barriers to implementing *Energy Efficiency Measures (EEMs)* culminated in the development of a model for identifying the barriers proposed by Cagno et al. (2013). This model proposes a taxonomy for the study of barriers, separating them into external factors (market, government, technology, suppliers of technology and financing system) and factors internal to the company (economic, behavioral, organizational, competence and awareness).

Various studies have looked at the relationship between energy efficiency variables and internal and external variables, the main results have been summarized in Table 1. The work of Kounetas and Tsekouras (2010) used the *Stochastic Frontier Analysis* (SFA) for manufacturers in Greece where they found a positive relationship between energy efficient technologies and the productive performance of manufacturers, but they found a negative relationship when the deterministic part of the frontier was analyzed. For productive performance, energy efficient technologies have a different effect when considering industrial sectors and company size. When the industries are intensive users of energy, the adoption of *Energy Efficient Technologies* (EETs) has a positive impact on performance, but the opposite occurs when the industries are not intensive users of energy.

In the survey by Suk et al. (2013), in energy intensive Korean companies, using a factorial analysis and logistic regression, no relationship was found between the external factors (regulation, competitors and associations) and energy savings. The energy saving practices are determined by upper management as well as training and economic incentives. Medium and large-sized companies adopt the best practices in EETs. Liu et al. (2013) in a survey in China using econometric techniques (multiple regression) a negative relationship was found between the price of energy and the acceptance of carbon tax costs and a positive relationship between energy management strategies and these same costs. The acceptance of higher carbon taxes by industries are determined by subjective perceptions as well as self-motivation, likely due to the lack of training of internal management.

In another study in Spain and Slovenia using data from the (*European Manufacturing Survey*) through linear and ordinal regression, Pons et al. (2013) found no relationship between economic performance and energy efficiency, instead they found a positive relationship between environmental performance and energy efficiency. Also for Chinese companies Zhang and Wang (2014) using multiple, logistic and ordinal linear regression demonstrated that collaboration for reducing carbon emissions (*Industrial Symbiosis*) has a positive relationship with economic performance. These authors found that for this study in China environmental regulations have no effect on the reduction of carbon emissions.

In a broad study Eccles and Serafeim (2013) conducted an econometric analysis with over 3000 companies to examine the effect of sustainable practices on the financial performance of these companies. The result showed a negative correlation between financial performance and combined improvements in social and environmental factors, when innovation is not present.

According to Kannan and Boie (2003) the objective of the