An Analysis Of Eco-efficiency In Energy Use And CO_2 Emissions In The Swedish Service Industries

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ABSTRACT

This study determines the trends in energy efficiency and CO_2 emissions of the Swedish service sector, based on results from the Malmquist data envelopment model (DEA) using data at the 2-digit level of aggregation for the Swedish service industry over the study period 1993-2008. The results show that Swedish service industries increased energy consumption and CO_2 emissions during the study period, whereas energy and CO_2 emission intensities have decreased in recent years. Findings suggest that Swedish service industries have an excellent potential to increase energy efficiency and reduce CO_2 emissions. Second-stage panel data techniques show that energy taxes, investments and labor productivity have a significant and positive influence on energy and CO_2 emission intensities implying that changes that lead to increases in these economic variables lead to higher energy efficiency and lower CO_2 emission intensity. This analysis demonstrates the importance of designing and applying adequate energy policies that encourage better energy use and management in this sector for the goal of achieving a low carbon economy.

Introduction

The service sector has become an engine of economic growth and is one of the factors used to measure an economy's progress, quality, development potential and other aspects (Drucker, 2002; Karmakar, 2004; Stern, 2005). Worldwide, service industries represent 63.2% of the gross domestic product, occupy 41.9% of the labor force, consume 12% of energy and account for 9% of CO_2 emissions. Between 1974 and 2009, due to the structural changes accompanying the migration from manufacturing to service industries, energy consumption increased 69%. Electricity as a main energy source increased from 15% to 23% (IEA, 2008 and 2009; CIA, 2011).

In the service industries, several techniques have been applied to study energy use, CO_2 emissions, electricity consumption and barriers to adopting energy saving practices. Mairet and Decellas (2009) labord energy consumption trends in the French service sector using decomposition analysis[1], and concluded that the increase in energy consumption was mainly due to growth in the sector. Butnar and Llop (2010) evaluated changes in CO_2 emissions from the Spanish service sectors by applying an input–output subsystem approach and structural decomposition analysis. They showed that this sector increased CO_2 emissions mainly because of a rise in the emissions generated by non-services to cover the final demands of services. Collard et al. (2005) labord the effect of the use of information and communication technologies on electricity intensity in the French service sector using a factor demand model. They found that electricity intensity increased because of the use of computers and software. Schleich (2009) analyzed electric intensity in Germany and concluded that limited information about energy use patterns and potential energy efficiency measures are the most important barriers to improving energy efficiency in the service industries.

By analyzing trends in eco-efficiency, this study seeks to identify the main factors that determine energy efficiency and decreasing CO_2 emissions in the Swedish service sector. Eco-efficiency refers to the ability to generate more goods and services while using fewer resources and producing less waste and pollution; an important aspect is a reduction in the energy intensity of goods or services (WBCSD, 1992).

[1] Decomposition analysis is an approach that is useful for quantifying the contribution of various factors to a difference or change in outcomes in an accounting sense.

One important goal of this research is to help Swedish policymakers determine opportunities for energy efficiency and help encourage the design of effective energy policies to strengthen and motivate higher energy efficiency and lower CO_2 emissions in the service sector. At a high level, the approach used in this research applies various linear programming and econometric approaches to Swedish service sector data from 1993-2008. Energy efficiency and reductions in CO_2 emissions were labord with the Malmquist data envelopment analysis (DEA) model to assess eco-efficiency within a production theory framework in which energy is one of the many inputs used to produce outputs (Mukherjee, 2008; Zhou and Ang, 2008). The results and trends in eco-efficiency are then explained using an econometric panel data analysis.

The article is divided into three sections following this introduction. The first section describes the main data sources and methods used. The second section shows the main results in the context of Swedish service industries. The last section summarizes conclusions and policy implications.

Data And Methodology

Service industries (excluding electricity, gas and water supply, and transportation services), involve activities that take place in buildings other than manufacturing, agriculture and households. Offices, banks, schools, hospitals, retail establishments, hotels, restaurants, and computer and data processing centers are examples of facilities in the service sector (Krackeler et al., 1998; Suh, 2006).

A dataset for Swedish service industries was collected from Swedish statistics offices for the period 1993-2008[2]. The following variables were used: capital input, measured as a stock by taking the value of gross fixed assets (property, plant and equipment); labor, measured by the total number of persons employed in service activities; energy, measured as the final energy consumption by service activity measured in Terajoules (TJ)[3]; materials, measured by expenditures on materials, and CO_2 emissions, measured in metric tons. All monetary variables were standardized to euro values from 2005.

Methodology

The study was conducted in two steps: (i) the Malmquist DEA model was applied to determine relative efficiencies in energy use and decreased CO2 emissions; and (ii) econometric panel data techniques were used to establish factors that may influence trends in the energy efficiency and CO2 emissions of Swedish service industries. The use of these two methods combined allows for an analysis eco-efficiency. In the first stage indexes of eco-efficiency are calculated. The indexes express a comparison of inputs and outputs in terms of energy use and generation of desirable output (value added) and undesirable output (CO2 emissions). In the second stage, these indexes serve as the dependent variable in an econometric model to determine what factors should affect eco-efficiency (to increase or reduce); for example, factors include taxes, investments, energy sources, and economic productivity.

The Malmquist productivity index. The Malmquist productivity index (Malmquist, 1953) is based on the DEA. This index estimates the productivity of the service industries analyzed, allowing for changes in productivity to be broken down into changes in technical efficiency and changes in technological efficiency, which combined account for total efficiency (EC). The method was originally proposed by Caves et al. (1982) and refined by Fare et al. (1995). In principle, the Malmquist index computes the distance of individual observations (firms, for example) from an economic efficiency frontier generated by the DEA. This method has been applied to the measurement of productivity changes and to the measurement of eco-efficiency by various researchers (Zhou et al., 2010).

[2] The data was at the 2-digit level of aggregation from International Standard Industrial Classification Rev. 3.1.
[3] This includes end-use and transmission and distribution-associated energy consumption.

To describe this methodology in greater detail, we consider two periods, 's' and 't', where period *s* is the base period, and period *t* is used as the reference technology. In period *s*, a particular firm uses $x^s \epsilon R_+^M$ inputs to produce $y^s \epsilon R_+^M$ outputs, while in period *t* the input and output quantities used are x^t and y^t respectively. Applying the definition of distance functions, the index can represent the output distance function for a firm in period *s* as

$$D^s(x^s, y^s) = inf\left\{\theta \epsilon R : \left(\frac{x^s, y^s}{\theta}\right) \epsilon P^s\right\}, \quad (1)$$

where P^s is the output set, defined as $P^s = \{(x^t, y^t): y^t \text{ can be produced by } x^t\}$; and $D^s(x^s, y^s) \leq 1$ if and only if $(x^s, y^s) \epsilon P^s$. The same applies to the distance function in period t (for more details see Coelli et al. (2005)). Fare et al. (1995) defined the Malmquist index as follows[4] :

$$M_0^{s,t} = \left[\frac{D_0^s(y^t, x^t)}{D_0^s(y^s, x^s)} \frac{D_0^t(y^t, x^t)}{D_0^t(y^s, x^s)}\right]^{1/2}, \quad (2)$$

where $D_0^s(y^t, x^t)$ signifies the output distance from the observation in period *t* to the period *s* technology; $D_0^t(y^s, x^s)$ signifies the output distance from the observation in period *s* to the period *t* technology. The Malmquist index in Equation (2) can also be further decomposed (as shown in Fare et al., 1995) into two components: one capturing efficiency change and another one capturing technological change, represented as a shift in the production frontier:

$$M_0^{s,t} = \underbrace{\frac{D_0^t(y^t, x^t)}{D_0^s(y^s, x^s)}}_{\textbf{Efficiency change}} \underbrace{\left[\frac{D_0^s(y^t, x^t)}{D_0^t(y^t, x^t)} \frac{D_0^s(y^s, x^s)}{D_0^t(y^s, x^s)}\right]^{1/2}}_{\textbf{Technological change}} \quad (3)$$

This represents the productivity of the production point (y^t, x^t) relative to the production point (y^s, x^s). A value greater than one will indicate positive Total Factor Productivity (TFP) growth from the period *s* to the period *t*. This index is the geometric mean of two output based Malmquist TFP indices.

The Malmquist index in Equation (1) is a product of three terms:

$$M_0^{s,t} = PE_0^{s,t} x\, SEC_0^{s,t} x\, TC_0^{s,t} \quad (4)$$

where $PE_0^{s,t}$ denotes the pure efficiency change, $SEC_0^{s,t}$ denotes the scale efficiency change and $TC_0^{s,t}$ denotes the technological change. Note that $M_0^{s,t} > 1$ denotes productivity growth, while $M_0^{s,t} < 1$ means productivity decline. The same applies for all the other components: $PE_0^{s,t} > 1$ means an increase in pure local efficiency (i.e. a firm has improved its catch per input in comparison to similar firms in the sample, and has also moved closer to the optimal scale of production), $SEC_0^{s,t}$ means an increase in scale efficiency (i.e. a firm has taken advantage of returns to scale by adjusting its size towards optimal scale) and $TC_0^{s,t} > 1$ means an increase in technology.

In this study, data for years 1993-2008 on 19 Swedish service industries was used in the DEA model. Each industry is treated as a firm or individual decision-making unit (DMU) in the analysis. The model evaluates eco-efficiency performance within a joint production framework in which both desirable and undesirable outputs, such as waste and pollution, are considered simultaneously. The input and output vector

[4] This form of the index is the geometric mean of the index proposed by Caves et al (1982).

x_0 is divided explicitly into every input component such as Capital (C), Labor (L) and energy (E). The value added of each service industry was used as a measure of desirable output and CO_2 emissions were used as a measure of an undesirable output. In this study, the reciprocal value of the undesirable output is used to incorporate the feature that more desirable outputs are preferred. In this model, when the score is equal to one the service sector is efficient, whereas scores below one represent lower efficiencies.

Panel data techniques for explaining results. As noted earlier, panel techniques are used to determine the factors that might explain differences in eco-efficiency levels across Swedish service industries during the sample period. The results of the DEA model are the dependent variables in several panel data models that included multiple determinants of energy efficiency and CO_2 emissions. The DEA scores are log-transformed due to the skewness of the DEA scores and to improve normality. To select the adequate panel model, we applied various tests. First, the F test was used on the pooled OLS model and the fixed effect model, and on that basis, we selected the fixed effect model. Next, we applied the Breusch and Pagan test of pooled OLS vs. the random effect model. Finally, we employ the Hausman test of fixed effect vs. random effect. The specifications of the tests to determine the proper panel data model indicated that the fixed effects estimation is adequate. The model used in this study is as follows:

$$RE_{i,t} = \alpha_0 + \alpha_1 ET_{i,t} + \alpha_2 FF_{i,t} + \alpha_3 INV_{i,t} + \alpha_4 PR_{i,t} + \alpha_5 KL_{i,t} + \varepsilon_{i,t} \qquad (7)$$

where $RE_{i,t}$ is the DEA score or energy intensity; $ET_{i,t}$ represents the expenditures in energy taxes applied to the Swedish service industry in period *t* for service industry *i*; $FF_{i,t}$ represents fossil fuel consumption; $INV_{i,t}$ are investments; $PR_{i,t}$ is labor productivity, measured as output per worker; and $KL_{i,t}$ is the capital input measured as the capital-labor ratio in period *t* for service industry *i*.

To determine whether the index and results obtained from the Malmquist DEA model and the panel data model estimations are robust, the following tests were applied: *Pesaran CD* (cross-sectional dependence / contemporaneous correlation) test to determine whether the residuals are correlated across entities; *a test for heteroskedasticity* to estimate the error process that may be homoskedastic within cross-sectional units calculating a modified Wald statistic for group-wise heteroskedasticity in the residuals of a fixed effects regression model; and *the Wooldridge test* for serial autocorrelation which determines the presence of serial autocorrelation as an indication that the dependent variable is characterised by persistent or mean-reverting dynamics, implying that omitted variables have a large impact on the dependent variable.

Results And Discussion

This section summarizes and discusses the results of the DEA and panel data models used to explore and explain the different factors that affect energy consumption and CO_2 emissions in the sector.

Results of the Malmquist DEA model. As shown in Figure 1 the annual average technical efficiency from the Malmquist DEA-model is 0.582. This suggests that the Swedish services industries have important potential to increase energy efficiency and reduce CO_2 emissions. The service sector could reduce energy input by nearly 42% on average, maintain the same levels of output and reduce CO_2 emissions without consuming any additional inputs. These results are consistent with the energy baseline in the 2030 scenario developed by European Commission (2008), which estimated that final energy demand of the service industries is projected to decrease between 30% and 60% in 2030.

The Malmquist productivity index and other indices for the period 1993–2008 in Swedish service industries are also shown in Table 1. The total productivity change score (the Malmquist index presented in column 1) is on average higher than one (1.01) indicating that several Swedish service industries experienced gains in productivity in the period considered. The change in the total efficiency score (column

2) is defined as the inclusion of best-practice technology in the management of the activity and corresponds to investment planning, technical experience, and management and administration in the service industries. For the period of study, the change in the total efficiency score is also higher than one, which signifies growth in efficiency during this period for the majority of Swedish service industries. The pure efficiency change (column 3) and scale efficiency change (column 5) show diverse results; various service industries obtain simultaneous gains in both areas while others obtain gains in one, but losses in the other. The improvement in pure efficiency indicates a better balance between inputs and outputs. The scale efficiency is dependent on industry size and increases in several service industries during the study period. Technological change (column 4) is the result of innovation through new technologies. This index is higher than one in the Swedish service sector indicating that innovation improved during the study period.

Figure 1. Technical efficiency from the Malmquist DEA model for the Swedish Service Industries

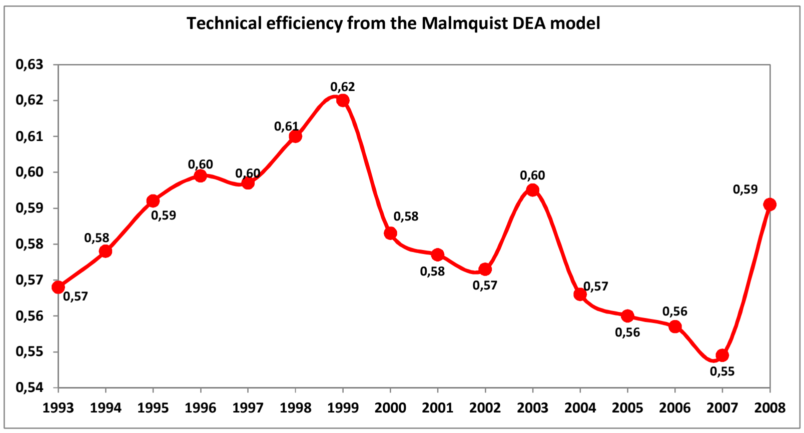

Table 1. Average of Total factor productivity (TFP), Total Efficiency (EC), Pure Efficiency (PE), Technological Change (TC) and Scale Efficiency Changes (SEC) in Swedish Service Industries over the study period (1993-1998)

	DEA model				
	TFP	**EC**	**PE**	**TC**	**SEC**
93-94	0.94	0.87	1.02	1.08	0.85
94-95	1.12	1.25	1.02	0.89	1.22
95-96	1.01	1.19	1.00	0.85	1.18
96-97	1.12	0.91	0.98	1.23	0.93
97-98	0.94	0.88	1.03	1.06	0.86
98-99	1.01	1.00	1.03	1.00	0.97
99-00	1.05	0.75	0.92	1.41	0.81
00-01	0.90	0.98	0.98	0.91	1.00
01-02	1.09	0.93	1.00	1.17	0.94
02-03	1.00	1.48	1.07	0.68	1.38
03-04	1.06	0.63	0.91	1.69	0.69
04-05	0.98	0.93	0.97	1.05	0.96
05-06	0.91	1.24	1.01	0.73	1.23
06-07	0.94	0.96	1.02	0.98	0.94
07-08	1.16	1.52	1.12	0.77	1.35
Annual Average	**1.01**	**1.03**	**1.01**	**1.03**	**1.02**

Note: A value greater than one indicate a positive growth or improvements in the index analyzed (efficiency and productivity); a value of one means there is no change and a value less than one indicates deterioration or decrease in the index analyzed from period *t* to period *t*+1.

Determinants of eco-efficiency in the Swedish service industries. Table 3 shows the results of the regression analysis for eco-efficiency, in which DEA results are the dependent variables. The estimations of residuals for fixed effects suggest the presence of heteroscedasticity and serial correlation according to Wooldridge test, Pesaran test and heteroscedasticity test that was corrected with Driscoll and Kraay standard errors for fixed effects. Fossil fuel consumption and labor are significant at the 95% or more.

As indicated by positive coefficients, the results of the regression indicate that higher energy taxes, investments and productivity lead to higher eco-efficiency in terms of energy efficiency and reduced CO_2 emissions. The negative coefficient on the fossil fuel consumption variable indicates this has an inverse relationship with eco-efficiency. In addition, the capital-labor ratio demonstrates a complementary relationship between energy and production factors.

Table 3. Results of the Regression Analysis for Eco-efficiency (Technical efficiency)

	Technical efficiency	
Parameters	Fixed effects	Driscoll-Kraay standard errors
Constant	2.629*** (0.255)	-0.217*** (0.730)
Energy Taxes	0.002 (0.014)	0.002 (0.013)
Fossil fuel Consumption	**-0.465***** (0.032)	**-0.465***** (0.083)
Investments	0.008 (0.007)	0.008** (0.002)
Labor Productivity	**0.065**** (0.023)	**0.065***** (0.036)
Capital-labor Ratio	-0.016 (0.023)	-0.016 (0.019)
F-test statistic	$F(18, 280) = 465.02$ 0.000 *Reject OLS*	
LM test Prob > $chibar^2$	$chibar^2(01) = 1804.52$ 0.000 *Reject OLS*	
Hausman test Prob>chi^2	$chi^2(5) = 14.84$ 0.011 *Reject RE*	
Test for heteroscedasticity [a] Prob > chi^2	LR $chi^2(18) = 483.77$ 0.000	
Wooldridge test for autocorrelation[b] Prob > F	$F(1, 18) = 16.744$ 0.000	
Pesaran's test	0.003	
No. Obs	304	304

Notes: Figures in the parentheses are standard errors.
***** Significant at the 1% level, **Significant at the 5% level**
[a]If Prob > $chibar^2$ < 0.05, indicate heteroscedasticity.
[b]If Prob > F > 0.05, indicate no serial correlation.

Energy taxes have a positive effect on eco-efficiency in terms of energy use and decreasing CO_2 emissions. In the Swedish service sector, energy taxes include the fuel and electricity taxes and the CO_2 tax. The Swedish taxation system is considered one of the most innovative and effective of those applied around the world because the taxes were indexed and linked to the consumer price index in Sweden (Speck, 2008).

Fossil fuels are included in the analysis to determine the role of these fuels in eco-efficiency. The results indicate that a decrease in fossil fuel consumption generates higher eco-efficiency in the form of higher energy efficiency and lower CO_2 emissions in the Swedish service industries. In other words, improved energy efficiency and decreased CO_2 emissions from Swedish industries has been generated by a shift from fossil fuels to low carbon or cleaner fuels as energy source.

Investments likely have a positive effect on eco-efficiency but are not significant because investments in the service sector have not primarily attempted to improve energy use or decrease CO_2 emissions. Labor productivity has a positive and significant effect on eco-efficiency, indicating that service industries with higher labor quality have higher energy efficiency and lower CO_2 emissions.

All of the findings in this study are important for designing suitable energy policies to increase energy efficiency and decrease CO_2 emissions in the service industries. The design and application of various strategies and policy instruments are important because energy consumption has grown most rapidly in this sector and it drives the increase in total energy consumption and CO_2 emissions for the whole Swedish industrial sector.

Conclusions

This paper demonstrated that the methods used to analyze eco-efficiency as a function of energy efficiency and CO_2 emissions can generate consistent, robust and reliable estimates from the Malmquist DEA model.

The results of the DEA analysis indicate that energy efficiency and CO_2 emission intensity varied across years and service industries in Sweden. While several service industries have increased eco-efficiency by increasing energy efficiency and decreasing CO_2 emissions, especially in recent years, this sector has the potential to further improve energy efficiency and decrease CO_2 emissions. The results of the panel data techniques suggest that increased energy taxes, investments, and productivity generate higher eco-efficiency, while higher fossil fuel consumption generates lower eco-efficiency. The capital-labor ratio shows a complementary relationship with energy.

Both this study's results and the literature on energy policy and determinants of energy demand in the service sector suggest that a package of policies and financial measures can contribute to the development of guarantee effective strategies leading to improvements in energy-efficiency performance and reduced greenhouse emissions in the Swedish service industries. Per the literature, the main strategies should combine: an integrated approach to energy and environment (Krackeler, Schipper, and Sezgen, 1998), mandatory standards (IEA, 2009), energy management, audits and other investments in energy efficiency in service enterprises, effective tax and tariff structures, and evaluation.

Further research is necessary at the sector level, focusing on identifying and understanding the barriers to adoption of energy efficient technologies, good practices and energy management systems as strategies to improve eco-efficiency. In addition, the methods and techniques used in this study should be applied in other countries and sectors to increase our understanding of the relationships between energy efficiency and CO_2 emissions and to further test the robustness and reliability of the results in order to build support for the role of eco-efficiency analysis in the formulation of energy and environmental policies.

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