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# Energy and environment efficiency of industry and its productivity effect

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A B S T R A C T

It is crucial for the industrial sector to achieve the multifaceted or composite efficiency of energy savings and the minimization of environmental wastes in the present circumstances of worsening global warming and resource depletion. Furthermore, the positive effects of composite energy efficiency on sustainable growth could lead to practical questions for the industrial sector, to ensure that it consistently uses its energy and resources effectively. The present research examines the positive contribution of this composite efficiency to the growth of final outputs in this sector, using the two-stage method of Malmquist efficiency analysis (MEA) and the linear regression of panel data from about 154 Korean industries from 2010 to 2012. The results found that composite efficiency and changes in the production factors have positive impacts on industrial productivity. In particular, relative efficiency has a positive influence on productivity, but technical efficiency does not have a significant impact. Our findings suggest that industries may voluntarily make efforts to improve their use of energy resources, but they also need to invest in energy technologies and develop efficient production structures, with the help of public policies.



## 1. Introduction

The acceleration of global warming and repetitive economic recessions signify that economic subjects must transform their rapid economic growth, based on input-intensiveness, into sustainable development with environmental protection. In particular, two energy crises—the crude oil shock in 1973, and the disaster of the Fukushima nuclear power plant in 2011—raise an insecurity problem that is associated with dependence on specific energy sources, and the systemic issue of environmental destruction from the excessive consumption of energy (Lee et al., 2016).

The global industrial sector consumes the largest amount of energy of all other social sectors (Abdelaziz et al., 2011), and Korea's industrial sector's energy consumption per GDP, and its consumption of petroleum, electricity, and coal, has continuously increased (KEEI, 2014). This high level of energy consumption and dependence on several resources can imply industrial fragility of the energy sector, which would be one of the fundamental uncertainties likely to harm the stable economic growth of industries (Acemoglu et al., 2015; Aldasoro and Angeloni, 2015). Furthermore, excessive energy consumption and its side effects, which include the emission of greenhouse gases (GHGs) and environmental destruction, can argue for industry's efficient use of energy and the environment for its self-sustainable development.

The industrial sector needs to acquire the multifaceted or composite efficiency of energy savings and the minimization of energy wastes, in response to increasing social concerns amid the recent energy crises and global climate change. Korea has been one of the top-ten heaviest energy-consuming countries in the world since 2012 (Lim et al., 2009), and the industrial sector has practical incentives for moving to composite efficiency, due to the fact that this sector has greater energy utilization than the rest of Korea's total energy consumption (Kim et al., 2011). In addition, the economic rationale for composite efficiency in this sector could be critical, because of two historic facts: World industries implemented the efficient expenditure of energy sources after the crude oil shock in the 1970s (Taylor et al., 2010) and Korean industries activated energy savings after the east Asian financial crisis in 1997 (Lim et al., 2009; Oh et al., 2010). Therefore, this research raises the following two research questions: Does the composite efficiency of

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energy and the environment contribute to the economic growth of industries? With regard to relative and technical efficiencies, which type of efficiency can influence industrial productivity?

The present study measured the composite energy and environmental efficiency (hereafter "composite efficiency") using Malmquist efficiency analysis (MEA), and a transactional dataset of 154 Korean industries from 2010 to 2012. This research investigated the positive contribution effect of composite efficiency to the growth rate of final outputs in the industries with feasible generalized least squares (FGLS), and other linear regression analyses, of panel data. Our analyses found that composite efficiency and production factors have a positive impact on industrial productivity. Of composite efficiency, relative efficiency also has a positive influence on productivity, but technical efficiency does not have a significant effect on the growth rate of the final outputs of industries. This positive relationship between composite efficiency and productivity can imply that industries have an economic incentive to voluntarily make improvements in efficiency. However, since technical efficiency does not have an impact, industries can be required to invest in the R & D of energy technologies and innovative changes in the energy-relevant behavior of supply and demand under the sustainable development of the energy trilemma's supply security, economically affordable pricing, and environmental soundness (Ang et al., 2015).

## 2. Literature review and hypotheses development

The sustainable growth of the society naturally requires industries to achieve the multifaceted efficiency of energy consumption and environmental protection. The historic relationships between the outputs of economic development and the inputs of energy consumption in many countries have empirically shown the environmental Kuznets curve of inverted u-shape distribution, which national energy consumption has increased with its outputs, but the volumes consumed have decreased at a certain level of economic growth (Dinda, 2004; Kijima et al., 2010). These improvements in energy intensity and efficiency seem to be the result of the economic subjects' integrated efforts to provide systemic management of energy's supply and demand, technological advancements, and structural energy savings (Dinda, 2004).

Previous research has concretely investigated this relationship between energy efficiency and economic development, as the verification of four hypotheses of economic growth through efficiency, feedback between efficiency and development, energy conservation through development, and independent relationships between efficiency and development (Ozturk, 2010). Among these suppositions, the literature has predominantly confirmed the growth hypothesis that national energy efficiency leads to economic growth (Omri, 2014; Ozturk, 2010). This study assumes this hypothesis that industrial economic growth results from energy efficiency, and analyzes the productivity effect of composite efficiency on industries in the following sections.

Energy efficiency can have two types of impacts on energy savings in terms of the absolute amount of inputs, and minimizing the by-products of energy or environmental wastes in the energy supply and demand chain. The emission of GHGs is one of the representative sources of environmental destruction from energy consumption, and carbon dioxide (or $CO_2$) is the major component of environmental wastes, and accounts for more than 75% of GHGs (GIR, 2015; IPCC, 2006). Therefore, this unavoidable production relationship of energy consumption and $CO_2$ appears to be an essential factor when researchers measure the energy efficiency of the economic subject. Relevant research has utilized data envelopment analysis with multiple outputs of positive and negative performances, and numerous inputs in cases of 35 OECD countries' efficiencies (Prieto and Zofío, 2007) and industrial efficiency in US manufacturing sectors (Egilmez et al., 2013).

Industries' composite energy and environmental efficiency can contribute to national economic development (Chen and Golley, 2014), but the degree of industrial efficiency could be inconsistent with the overall efficiency in a country (Gross, 2012). Because an individual industry can have a unique production structure for the intensity ratio of its outputs and inputs, and its appropriate energy mix, different technologies or production structures of energy sources can result in discrepancies among industries, and between the industry sector and a nation (Liu and Ang, 2007). Several major variables that affect an industry's composite energy and environmental efficiency could be the total consumption of energy and concentration of available energy (Kim and Kim, 2012; Lee et al., 2016; Sueyoshi and Goto, 2015). Therefore, this research posits Hypothesis 1 about the positive relationship between composite energy and environmental efficiency and industrial productivity with the support of the previous finding on efficiency-leading growth (Omri, 2014; Ozturk, 2010).

**Hypothesis 1(H1).** Industries' energy and environmental efficiency will positively affect their changes in final outputs.

The costs of labor, fixed capital, and other production factors can also have positive effects on the final outputs of industries (Choi et al., 2012; Sueyoshi and Goto, 2015; Zhou et al., 2012). This research posits Hypothesis 2 regarding the positive relationship between traditional production factors and industrial productivity.

**H2.** Production features of industries will positively affect changes in their final output.

**H2-1.** Changes in the fixed capital of industries will positively affect changes in their final output.

**H2-2.** Changes in the labor costs of industries will positively affect changes in their final output.

**H2-3.** Changes in the value-added enhancements to industries' operations will positively affect changes in their final output.

## 3. Method and sample data

### 3.1. Overview

This research uses the two-stage MEA and FGLS, to measure Korean industries' composite efficiency, and the contribution of efficiency to industrial productivity (Fig. 1). MEA is used to calculate the industrial efficiency of energy and the environment by analyzing the relationship between two dependent variables and three independent variables as shown in Table 1. These factors of intermediate industrial outputs, $CO_2$ energy consumption, and non-energy inputs seem to be the variables traditionally used to study the industrial characteristics of production relationships in the input-output table (BOK, 2014b; Zhou et al., 2012).

After MEA is used to measure the composite efficiency, this study adopts FGLS and other linear regressions of panel data to analyze the relationship of one dependent variable of industries' growth rate of final output, and four independent variables of composite efficiency and production factors in Table 1. In particular, this research analyzes the contribution of this efficiency to industrial productivity in 154 Korean industries, from 2010 to 2012, with the dataset provided by input-output tables from the Bank of Korea (BOK, 2014a), and industrial emissions of $CO_2$ from the Ministry of Environment in Korea (GIR, 2015).