Chapter 1
Overview

1.1 Introduction

This book deals with an econometric specification and estimation of a dynamic factor demand model to address the effects of the relationship between ICT investment and energy use on the productivity of the South Korean industrial sector during the period 1980–2009.

The book aims at examining the different input factors in the production process for the South Korean industrial sector and compares them to the Japanese industrial sector. A special emphasis is placed on the relationship between ICT investment and energy use, as well as the impact of this relationship on productivity growth. It further aims at determining the extent to which input factors of production are complements or substitutes with each other, with a particular emphasis on the ICT investment and energy use and their relationship with other input factors of production.

This chapter introduces to the reader a general overview of this book. It starts with an introduction related to energy demand and consumption worldwide, and then explicitly states the problem and purpose of the research. It then describes the structure of this study, the research questions and the related hypotheses, and assumptions and limitations.

The significance of this subject is imperative to five groups of participants in the market, namely, (i) environmental policy makers; and in its message to industrial sector's stakeholders; (ii) the policy makers and (iii) the regulators; (iv) the new entrants or the investors who might be contemplating to enter the industrial sector, and (v) finally the energy consumers.

The overall consumption of energy worldwide is continuously increasing. According to the International Energy Outlook Report published in 2016 (IEO 2016) by the US Energy Information Administration (EIA), energy consumption will continue to increase worldwide by 48% in 2040. In 2008 the total energy consumption was 505 quadrillion Btu (British thermal unit). It is expected to reach

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770 quadrillion Btu by the year 2035 (EIA 2011), and to 815 quadrillion Btu in 2040 (EIA 2016). This steady increase in energy demand will negatively affect the environment and the availability of depletable energy sources of fuel, or more specifically, the primary energy needed to produce energy output such as electricity.

The estimated world energy demand by region for the periods 2008–2035 and 1990–2040 are shown in Table 1.1 (the 1990–2012 numbers are actual energy demand) and Table 1.2 (the 2008 numbers are actual energy demand), respectively. This noticeable increase in energy consumption is due to rapid economic development, industrialization, and population growth, especially in developing countries such as China and India with a vast population size.

Strong economic development leads to an increase in the demand for energy in the industrial sector. The industrial sector consumes at least 37% of the total energy supply, which is relatively more energy intensive than any other major sector including the household, agriculture and public services sectors (Abdelaziz et al. 2011; Friedemann et al. 2010). A study conducted by the US Environmental Protection Agency (EPA) in 2007 revealed that 30% of the energy consumed by industrial and commercial premises is wasted due to inefficient use and a lack of risk management tools (Environmental Protection Agency EPA 2007).

Energy use efficiency is an important issue, due to a limit in the replacement of energy as an input factor with other possible substitutable factors in the production process. The efficient use of energy may reduce the amount of fuel or primary energy needed to produce energy output, such as electricity. This will reduce the energy intensity, which may contribute to a reduction in the corresponding global emissions of air pollution and greenhouse gases (EIA 2011).

Table 1.1 World estimated energy demand 2008–2035 [in Quadrillion Btu (Btu is an acronym for British thermal unit. It is used to measure energy consumption and defined as the amount of energy required to heat one pound of water by one degree of Fahrenheit (EIA 2013))]

Year Region	2008	2015	2020	2025	2030	2035	Average Annual % Change 2008–2035
OECD	244.3	250.4	260.6	269.8	278.7	288.2	0.6
Americas	122.9	126.	131	135.9	141.6	147.7	0.7
Europe	82.2	83.6	86.9	89.7	91.8	93.8	0.5
Asia	39.2	40.7	42.7	44.2	45.4	46.7	0.6
Non-OECD	260.5	323.1	358.9	401.7	442.8	481.6	2.3
Europe and Eurasia	50.5	51.4	52.3	54	56	58.4	0.5
Asia	137.9	188.1	215	246.4	274.3	298.8	2.9
Middle East	25.6	31	33.9	37.3	41.3	45.3	2.1
Africa	18.8	21.5	23.6	25.9	28.5	31.4	1.9
Central and South America	27.7	31	34.2	38	42.6	47.8	2

Source EIA (2011)

Table 1.2 World estimated energy demand 1990–2040 (in Quadrillion Btu)

	Non-OECD	OECD
History 1990	154.94	201.06
2000	173.59	236.21
2012	310.83	238.44
Projections 2020	375.01	253.94
2030	450.50	267.23
2040	532.84	282.12

Source EIA (2016)

This Book investigates the impact that different input factors of production have on the market, as well as the impact of consumer and producer characteristics on energy demand in the industrial sector for South Korea over the period 1980–2009, with a special emphasis on the effects of ICT capital investment on the demand for energy. In addition to that, it analyses the productivity growth of the industrial sector to identify the sources of growth through decomposing the Divisia index based on total factor productivity (TFP) growth into different effects, by employing a dynamic factor demand model. This will enable producers and policy makers to evaluate different alternatives for reducing energy consumption and using energy in a more efficient manner.

A key variable of interest in a study of efficiency and productivity in the industrial sector is the energy demand. It can be considered a significant variable in the cost structure of any industry, in which it is considered an essential determinant of the level of energy demand (Allan et al. 2007; Fleiter et al. 2011; Mukherjee 2008).

This study consists of two parts. In the first part a comparative analysis is conducted using a dynamic factor demand model for Japan and South Korea. Having Japan as a comparative based country will allow the investigation of the catch-up process and show how South Korea has developed and caught up with Japan over the last three decades.

The measures of productivity with a single factor, such as labor or capital productivity, have the advantage of simplicity. However, these measures ignore the substitution effects between factors of production, and can generate interpretation problems (Grosskopf 1993). The TFP is a measure of overall productivity change, which is a weighted average of each single factor of productivity growth. Hence, the second part of this study uses the TFP as a measure of productivity and decomposes the TFP growth for the South Korean industries using a dynamic factor demand model estimated with non-linear Full Information Maximum Likelihood (non-linear FIML) estimator. The TFP growth is estimated parametrically and decomposed into different components. The TFP growth is decomposed into four different components: (i) Technical change effect, (ii) scale effect, (iii) temporary equilibrium effect, and (iv) direct adjustment cost effect.

1.2 Why This Study

The impact of energy prices' uncertainty on economic growth is dated back to early theoretical foundations which explained that energy prices uncertainty will lead to more optimization of firms and industries to postpone irreversible investment decisions (Bernanke 1983; Henry 1974). Oil price uncertainty may encourage consumers to postpone decisions to purchase durable goods, to increase precautionary savings, and also to depress broad measures of current consumption.

The uncertainties associated with future oil prices are reflected in the international energy outlook report 2016 by including a low oil price and a high oil price cases. According to EIA (2016), oil prices have fallen since 2011 from about 115 USD per barrel to 50 USD per barrel in 2015 but are expected to raise again to reach 141 USD per barrel in 2040. In the case of high oil prices, the steady increase in the demand for energy leads to an increase in energy price. This increase in energy price, according to the report, is due to an increase in the demand for oil and in the production cost. In the other hand, for the low oil price case, a combination of lower economic activity and low oil prices will encourage consumers to consume more energy. Hence, the industrial policy decision makers need to understand the importance of energy in the industrial production structure in order to assess and formulate the necessary energy conservation measures. Accordingly, it is essential to acquire knowledge about the energy demand and its characteristics, such as the possible substitutability between energy and other factors of production (Dargay 1983; Koetse et al. 2008).

A tremendous growth in the use of ICT equipment in all aspects of life is witnessed since the last two decades. ICT is being used in industrial, commercial, and residential sectors, in which it has become heavily dependent and an integral part of human's daily lives (Zeadally and Chilamkurti 2012). Moreover, the ICT has witnessed advanced improvement, diffusion, and use in all areas of production, distribution, and consumption. It has spilled over into every industrial sector, including agriculture, water management, manufacturing, and most service sectors. It is considered to be one of the most important drivers of economic growth and effectiveness (Friedemann et al. 2010; Jaeger 2003; Vu 2011).

ICT is considered a driving engine of green growth due to its effects on raising resource and energy efficiency. ICT offers various functionalities such as the direct substitution of virtual process for physical process, system monitoring using censoring tools, data transmission and processing, and driving and control of equipment. Through these functions ICT enhance the decoupling of economic activities from energy use (Melville 2010; Schulte et al. 2014).

Recent trends emphasize toward supporting the ICT needs through efficient use of energy and reduce carbon emissions in the industrial sectors. This trend is mostly driven by different factors such as environmental issues and global warming, increase the demand for more power to support ICT equipment, increase in the price of energy, and increase awareness of national energy security (Zeadally and Chilamkurti 2012).

The importance of the rapid substitution toward ICT for other factors of production is due to the rapid decline in the ICT price. An average annual reduction of more than 20% in the ICT price provides a strong incentive for the substitution of ICT for other factors of production (Cardona et al. 2013; Jorgenson and Stiroh 1999). Indeed, this recent improvement and increase in the diffusion of ICT capital goes together with a reduction in energy intensity in the production, defined as the consumption of energy-to-output ratio (or consumption of energy-to-value-added ratio). According to Romm (2002), the US GDP and energy use grew together at an annual average rate of growth 3.2 and 2.4%, respectively, in the pre-internet era (1992–1996), while the growth was reported to be 4 and 1% during the internet era (1996–2000). As reported by Laitner (2002) the energy intensity was 4.4%, while it was only 0.8% for ICT sectors in 1996.

Energy use as another important factor of production and a source of economic growth and effectiveness has also improved following the increase in the use of ICT in production. Energy use has continuously improved following the increase in the use of higher technology in production, as well as in response to the increase in the price of fuel (Soytas and Sari 2009; Stern 2011). The energy sector is undergoing reforms aimed at using more advanced technology in the generation, transmission, and distribution stages (Fukao et al. 2009). The aim of such reforms is to increase energy efficiency by reducing the cost of generation and waste in the transmission and distribution stages of energy production (here referring mainly to electricity as a source of energy).

Accordingly, these evidences raise the question of the existence of a possible causality between these two factors, going from the diffusion of ICT capital goods to the decrease in energy intensity of production. At first look, one may be tempted to reject such a potential causality, as ICT equipment are electricity consuming devices. For example, in 1995, personal computers and terminals were consuming 13% of the electricity used by commercial premises in the US, the same amount as air-conditioning. The US showed a 3.2% annual growth in electricity demand during the period 2001–2010 for office equipment, compared to 1.4% for the US economy as a whole (EIA 2011). However, from a broader perspective, as discussed by Collard et al. (2005), the net effect of ICT diffusion may be more difficult to evaluate given the uncertainty of its consequences on productive and social structures.

Industrial sectors in general directly generate CO_2 while ICT in contrast generates ICT indirectly by using electric power for ICT equipment and infrastructure (including cooling). As a result, different strategies are adopted aiming at improving energy use efficiency. Such strategies may enhance the reduction of environmental impact of ICT use and to help energy suppliers to improve long term profitability (Zeadally and Chilamkurti 2012). The energy conservation related to ICT diffusion is divided into two types that are rather difficult to quantify, these are: (i) energy conservation from efficiency (this can be observed from better management of an assembly line that would be permitted by ICT), and (ii) energy conservation as a result from structural changes (this would come true if for example end-users use less cars and other transportation means to go to shopping malls and instead rely on the Internet to shop) (Romm 2002).

Unlike normal goods where the supply response is used to meet an increase in demand, in the case of energy, the market demand response is employed to reduce the increase in demand. For example, the use of smart grid technology as part of a demand response program allows for the application of price variation/discrimination by the type of consumer, location, season, and hours of the day, with the aim to reduce energy consumption. It improves the producer's and consumer's ability to optimize the generation and consumption of energy. Better optimization not only improves energy use and efficiency, it will also reduce energy generated by the peak time reserve capacity at a high cost, and also reduce energy consumption during peak times at a high price (Heshmati 2013; Khayyat 2015).

The current study aims at developing a better understanding of the relationship between ICT capital investment and energy demand. Since some energy types (e.g., electricity and natural gas) cannot be stored, this will help to identify optimal investment in ICT and optimize energy consumption.

1.3 Objectives

The input factors of production in economic theory are often divided into two main components: The primary component, or so-called the production factors, consists of non-ICT capital and labor inputs, while the secondary component is the intermediate inputs, this component consists of factors such as materials, ICT capital, supplied services, and energy input. Energy as an intermediate input factor affects changes in productivity, while the efficiency of energy use will affect single and multiple, or total, factor productivity (Dimitropoulos 2007).

Energy is considered an essential factor in the manufacturing industry's production. It is also an important factor in the production process, as it can be used directly to produce final goods (Khayyat 2015). The intensity of energy use in the modern production technology is a critical issue, as the latter is often using energy in an intensive way (Stern 2011; Zahan and Kenett 2013).

The objective of this study is to examine the effects of different input factors in the production process for the South Korean industrial sector and compare them to the production process of the Japanese industrial sector. A special emphasis is placed on the relationship between ICT investment and energy use, as well as the impact of this relationship on productivity growth. The elasticity of input factors and output are also studied. Structural changes in various input demand patterns are then explored for different periods and decades. In addition, this study aims at determining the extent to which input factors of production are complements or substitutes with each other, with a particular emphasis on ICT and energy inputs and their relationship with other input factors of production (e.g., labor, non-ICT capital, and materials) in the production process (Example of similar studies, see: Arnberg and Bjorner 2007; Kander and Schön 2007; Khayyat 2015; Koetse et al.

2008; Ma et al. 2008; Pindyck 1979). The pattern of substitutability or complementarity will be useful to assess and determine the level of energy demand and to identify the sources of productivity growth.

This study based on the theory of production utilizes a panel data approach with descriptive statistics to identify and define the specific independent variables that significantly related to the dependent variables. The study focuses on 30 main industrial sectors in South Korean and Japan.

1.4 Research Significance

This study addresses mainly four aspects of production and energy demand in manufacturing: First, it will establish a relationship between different input factors of production. Second, it will investigate whether the energy demand in the industrial sector in South Korea can be decreased/increased by substituting/complementing with other input factors of production such as ICT capital and labor. Third, it will look at the sources of productivity growth in the industrial sector through decomposing the Divisia index based TFP. Finally it provides appropriate policy recommendations based on the findings.

The significance of this subject is imperative to five groups of participants in the market, namely, (i) The environmental policy makers, and in its message to industrial sector's stakeholders, (ii) The policy makers and (iii) The regulators, (iv) The new entrants or the investors who might be contemplating to enter the industrial sector, and finally, (v) The energy consumers.

The environmental policy makers will benefit from this study through the following: First, it helps to identify the factors that increase energy demand (through complementarity relation), in which it leads to an increase in greenhouse gas emission. Second, to include these factors into existing programs of energy conservation and efficiency enhancement, toward lowering the greenhouse gas emission and fossil fuel switching, to use of renewable energy and programs for nuclear and carbon capture and storage.

The policy makers of the industrial sector's stakeholders will benefit from this study from two aspects: First, by directing necessary public supports to increase the energy use efficiency, and thereby reduce energy consumption and dependency, and second, to provide justifications to increase the share of renewable energy in the energy mix, as it requires policies to stimulate changes in the energy system.

The regulators from the industrial sector's stakeholder may benefit from this study to introduce new or update existing regulatory frameworks regarding for example public utilities, standards for fuel economy, and to provide subsidies to potential investors and producers of alternative fuels.

Moreover, this study can be an input for investment decisions by new entrants to the industrial sector business through the following: First, in providing basic data in order to set up business strategies. Second, to efficiently allocate the amount of energy used in the production, and third, to employ enough amount of ICT capital and new technology (if substitutability pattern is observed) that help in producing the same amount of production with less energy use.

The energy consumers especially energy intensive industries may use this study to be able to reduce their energy consumption, to make a tradeoff between the consumed amounts of energy versus employing other factors that substitute energy. This tradeoff may lead to efficiency in their energy consumption.

Finally, the results from this study can add to the bodies of knowledge for the industrial sector worldwide especially in the high energy consumed countries such as China, US, and India, and high energy consumed countries of OECD and non-OECD, with energy intensive production structure to identify alternatives to propose strategies for low carbon economy and production structure. In order to confront possible future energy crises, the consumption of energy should be restructured and reduced.

Figure 1.1 shows the top 10 GHG emitters countries based on their total annual emissions. According to the figure, China is the most GHG emitter country followed by the USA and EU countries (Ge et al. 2014). Moreover, as depicted byo Finley (2012), the largest source of increased energy consumption is China, where it is estimated to grow up to 50% by the year 2030 in its oil consumption. This vast growing is expected to remain in the industrial sector. China is expected to implement policies to slow the growth rate of oil consumption.

Policy and strategies are needed to achieve the stated goal. It is necessary to know how certain factors for example ICT capital can be used to reduce the energy consumption, and how to quantify and assess this impact. In the aftermath of Oil Crisis, Europe was able to reduce its energy use and dependency through improvement in the energy use efficiency and diversification of its energy sources (Favennec 2005; Terrados et al. 2007). In the periods of economic shocks that witness extraordinary energy price changes, it is difficult to apply the traditional econometric models to explain the behavior of the energy demand. Advanced

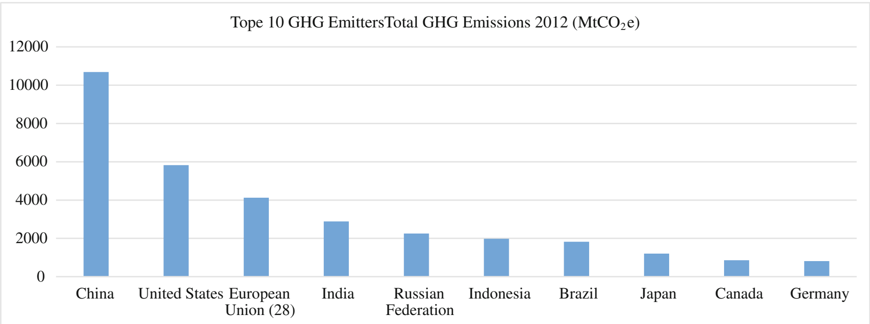

Fig. 1.1 Tope 10 GHG emitters. Total GHG emissions 2012 (MtCO$_2$e: Million metric tons of carbon dioxide equivalent. This measure can aggregate different greenhouse gases into a single measure, using global warming potentials. One unit of carbon is equivalent to 3.664 units of carbon dioxide)

methods such as dynamic model specification is highly desirable, as it allows for flexibility in adjustment of the input factors in the long-run (Kim and Labys 1988). Although the dynamic model formulation may lead to increase complexity in modeling, estimation, and interpretation of the results, it may have the advantage of deriving the elasticities as well as accounting for responsive heterogeneity over time and by industry characteristics.

1.5 Research Design

The research design for this study is quantitative, correlational, and descriptive. It is based on existing literature of dynamic factor demand models, an existing strand of literature that constructs the relationship between energy demand with other input factors of production, (see for example: Apostolakis 1990; Dietmair and Verl 2009; Field and Grebenstein 1980; Frondel and Schmidt 2002; Imran and Siddiqui 2010; Kuemmel et al. 2008; Park et al. 2009; Pindyck 1979; Zahan and Kenett 2013).

The review of relevant literature, as well as other studies analogous to studies by the authors quoted above on production functions (Berndt and Wood 1975, 1979; Christensen et al. 1973; Griffin and Gregory 1976), and exploratory research through the analysis of secondary data and longitudinal design, served as key inputs for the design of this study. These studies provide knowledge on applying a quantitative, correlational, descriptive study and in applying the different forms of factor demand modeling.

Accordingly, this study employs the knowledge gained from reviewing the previous literature and provides an all in one study using a quantitative, correlational, and descriptive approach. As described by Johnson (2001), in order to establish a wide range of basic knowledge for the dependent variables based on the existing literature in determining the production and energy demand. A correlational, descriptive, quantitative analysis is conducted to examine a panel data sample from a secondary data source for 30 main industries in South Korea and Japan over the period 1980–2009 and 1973–2006, respectively.

A secondary data analysis is a noticeable time and cost-effective tool for data collection. Researchers with limited funding can access a huge dataset for a small cost in a relatively timely manner, compared to other means of data collection, such as a survey, which typically requires more time and an expensive planning process in addition to data mining and documenting (Dale et al. 2008). The panel data was collected from different Microsoft Excel spreadsheets mainly provided by the Asia KLEMS and EUKLEMS growth and productivity account databases. The data was then complied into a single spreadsheet for the initial statistical analysis (descriptive statistics). Finally, a detailed analysis using SAS codes was conducted. Hence, the study aims at exploring the relationship between variables in the panel dataset, and by doing so, a quantitative analysis is applied.

1.6 Research Questions and Empirical Motivations

This study addresses four research questions with respect to the production technology and the nature of the productivity growth in the South Korean industrial sector. The research questions are formulated as follows:

1. What is the relationship between the ICT capital investment and energy use in the production process of the South Korean industrial sectors?
2. How far the levels of the ICT investment and energy use are from their optimal values in the production process of the South Korean industrial sectors?
3. How the structure of the South Korean industrial sectors' factor demand can be described?
4. What is the major source of the total factor productivity growth in the South Korean industrial sectors?

The empirical motivation behind the research questions is that there is little knowledge about the relative importance of energy in the South Korean industrial sector when it comes to industry heterogeneity and stochastic shocks, such as oil shocks or financial crisis (Benjamin and Meza 2009; Khayyat 2013). Further motivation is due to the continuous debate over the issue whether energy and other input factors, such as ICT capital, are substitutes or complements. The inconsistencies in the results are still controversial and need further investigation (Koetse et al. 2008; Thompson and Taylor 1995; Welsch and Ochsen 2005).

Different hypothesis derived from the formulated research questions will be tested based on a dynamic factor demand model with panel data estimation for 30 main industries in South Korea over the period 1980–2009. In addition, several other determinants of ICT capital and energy use levels and efficiency will be identified and their impacts will be estimated. The differences in the responsiveness to other determinants by industry can be exploited for the purpose of policy analysis.

1.7 Assumptions and Limitations

This section outlines different types of assumptions and constraints made in completion of this study: Methodological and econometric assumptions, theoretical assumptions, topic-specific assumptions, and assumptions about instruments used in the empirical estimation. The limitations of the design illustrate the boundaries of the study and its generalizability to other factors of production, economic sectors, and countries.

1.7.1 Energy Price

The energy policy of the South Korean government aims at securing energy supply at a low cost. The price of electricity, gas, and fuel are highly regulated by the government, and hence, the variability of price may fail to act as an applicable indicator for both the demand and supply sides of consumers' and producers' responses to price changes.

The energy demand will be determined by supply constraint, not by the ordinary law of supply and demand. Countries such as South Korea, which rely heavily on imports for their energy use, are mostly incorporating non-market based mechanisms rather than energy price to stabilize their local energy market (Cho et al. 2004; Khayyat 2013; Kim and Labys 1988).

1.7.2 Methodological and Theoretical Assumptions

Some specific assumptions are needed in order to formulate the factor demand model for this study. The explanatory variables used to formulate the factor demand model are assumed to be independent from each other, but highly correlated with the dependent variables. Another assumption is related to the variable materials which is assumed to be weakly separable from the other input factors (i.e., non-ICT capital, labor, energy, and ICT capital).

In this study it is assumed that industries are maximizing their profits through maximizing production output and minimizing the inputs used in the production process (hiring the optimal input to minimize the production cost of producing a given amount of output). Finally, the market is assumed to be perfectly competitive. These assumptions permit the construction of the dynamic factor demand model in this study.

1.8 Operational Definitions

Different terms are used throughout this book, a brief definition for each of these terms is provided as follows (definitions are listed in alphabetical order):

1. Allocative Efficiency: The allocative efficiency is defined by Heshmati (2003) as a firm's capability to equate the marginal cost with its marginal value of product.
2. Btu: An acronym for British thermal unit, it is used to measure energy consumption and defined as an amount of energy required to heat one pound of water by one degree of Fahrenheit.
3. Coefficient of Determination: A measure used in the regression analysis often knows as R-square (R2), it measures the proportion of the variability in the response that is explained by the explanatory variables. It can be defines as

$1-(SSE/SST)$ where SSE is the residual (error) sum of squares and SST is the total sum of squares that is corrected for the mean (Wooldridge 2006).

4. Cross Price Elasticity of Demand: It is defined as the change in energy demand with respect to change in price of substitutes (Allen et al. 2009):

$$E_{PS} = \frac{\Delta E}{\Delta PS} \cdot \frac{PS}{E} = \frac{E_t / E_{t-1}}{PS_t / PS_{t-1}} \cdot \frac{PS}{E} \tag{1.1}$$

5. Where E_{PS} is the cross price elasticity of demand, E, E_t, and E_{t-1} are energy variable, energy variable at time t, and energy variable at time $t-1$, respectively, PS, PS_t, and PS_{t-1} are price of substitutes, price of substitutes at time t, and price of substitutes at time t-1, respectively. ΔE and ΔPS are changes from time t-1 to time t for energy and price of substitutes, respectively.
6. If the measure above is positive, the two goods are said to be substitutes. The demand for energy increases as the price of the other goods increase. While a negative cross price elasticity implies that goods are complements, the demand for energy decreases if the prices of other goods increase.
7. Cross Price Elasticity of Substitution: It is another measure used for the degree of substitutability between input factors of production. It measures a proportional change in quantity of input factor. It is a change that results from changes in the price of other input factors used in production. This measure is more appropriate for policy issues in comparison to the partial elasticity of substitution's measure (Saicheua 1987).
8. Efficiency: Is a measure of the firm's ability to produce output in comparison to firms with the best practice technology.
9. Economic Efficiency: Is a measure of overall efficiency which is decomposed into technical and allocative efficiency components. It is measured as the product of the two components (Heshmati 2003).
10. Firm Performance: The firm's performance is a concept depending on economic efficiency, in which it consists of two parts, technical efficiency and allocative efficiency (Heshmati 2003).
11. F-test: A statistical test used to evaluate a model's performance to test whether one or more explanatory variables used in the model is contributing to the model's explanation of the dependent variable. It can be also used to compare two models when one model is a special case (nested model) of the other model (Lomax 2007).
12. Inefficiency: Is a measure of percentage degree of inability to produce output compared with the firm that has the best practice technology.
13. Multicollinearity: A statistical phenomenon often used when the explanatory variables that are needed to construct a regression model is linearly related with each other. A regression model with high correlation between two or more explanatory variables is suffered from multicollinearity problem. In the presence of multicollinearity, the estimated coefficients will be sensitive to any change in the model specification or in the data; hence, the predicted estimates

will not be efficient in predicting the outcome of the model (O'Mahony and Timmer 2009; O'brien 2007; Wheeler and Tiefelsdorf 2005; Wooldridge 2006).

14. MSE: Mean square error, it is the variance of the error term calculated as the proportion of the residual sum of squares (SSE) to the degree of freedom defined as the difference between the number of observations and the number of parameters. MSE can be expressed as SSE/(n−k), where n is the number of observations and k is the number of parameters (Lomax 2007). The standard deviation of the dependent variable can then be calculated taking the square root of MSE and is defined as Root MSE.
15. Output Elasticity of Energy Demand: The output elasticity of energy demand is a measure that explains the change in energy demand as a response to change in total production (Allen et al. 2009):

$$E_Y = \frac{\Delta E}{\Delta Y} \cdot \frac{Y}{E} = \frac{E_t/E_{t-1}}{Y_t/Y_{t-1}} \cdot \frac{Y}{E} \tag{1.2}$$

16. Where E_y is the output elasticity of energy demand, Y, Y_t, and Y_{t-1} are output variable, output at time t, and output at time t−1. E, E_t, and E_{t-1} are energy variable, energy variable at time t, and energy variable at time t−1. ΔE and ΔY are changes from time t−1 to time t for energy and output, respectively.
17. Eyis positive in general because any increase in total output implies that more input is demanded. $1/E_y$ (inverse) indicates returns to scale. An inverse value less than one indicates an increasing return to scale, while a value higher than one indicates a decreasing returns to scale (Kumbhakar et al. 1997).
18. Outsourcing: It measures the amount of goods and services produced previously in-house that are outsourced to outside suppliers (Heshmati (2003).
19. Productivity: The productivity of a firm is defined as the ratio of the output produced to the input used to produce the output, i.e., Productivity = Output/Input. As emphasized by Coelli and Battese (1998), this relationship is simple to obtain when the production process involves only one output produced by a single input. For multiple inputs used to produce one or more units of outputs then the requirement to obtain a measure of productivity relation is that the inputs should be aggregated to obtain one single index of input. The most known factor productivities are labor and energy.
20. Production Possibilities Frontier (PPF): The production frontier is defined as a graph that shows all possible combinations of simultaneous produced goods in a given time period assuming all other factors held constant (Kumbhakar and Lovell 2000).
21. Partial Elasticity of Substitution: A measure used for the degree of substitutability between input factors of production. It was first found by Allen (1938). It measures the proportionate change in the relative input factors shares that caused by the proportionate changes in the relative price of these factors (Knut and Hammond 1995; Saicheua 1987).

22. Price Elasticity of Energy Demand: This can be explained as a measure of how a change in price of energy will change the amount of energy used in the production. If the measure is greater than one, the demand is elastic, which means the higher the energy price, the more energy demand is reduced; less than one then the demand is inelastic, the higher the energy price, the less of energy demand will be reduced; or equal to one, which means unit elastic (Allen et al. 2009). Mathematically, the price elasticity of energy demand called often own price elasticity and can be expressed as follows:

$$E_{PE} = \frac{\Delta E}{\Delta P} \cdot \frac{P}{E} = \frac{E_t / E_{t-1}}{P_t / P_{t-1}} \cdot \frac{P}{E} \tag{1.3}$$

23. Where E_{PE} is the price elasticity of energy demand, P, P_t, and P_{t-1} are price variable, price at time t, and price at time t−1. E, E_t, and E_{t-1} are energy variable, energy variable at time t, and energy variable at time t−1. ΔE and ΔP are changes from time t−1 to time t for energy and price, respectively. The sign in general is negative as the demand curve is used to have a negative slope, implying an increase in energy price reduces demand for energy. If the variable E and P are expressed in logarithms, the elasticity is directly interpretable as percentage change in demand in response to a percent increase in price of energy without the second component ratio. It can be expressed as:

$$E_{PE} = \frac{\partial \ln E}{\partial \ln P} \tag{1.4}$$

24. The Rate of Technical Scale: It is defined by Strassmann (1959) as the productivity's rate of change resulted from changes in the production technology or technique. It measures increase in production from proportional (one percent) increase in all inputs. The measure equals to one, less than one or higher than one indicates constant, decreasing, or increasing returns to scale, respectively.
25. toe: An acronym for Ton of oil equivalent, it is used to measure energy consumption, an amount of energy released by burning one ton of crude oil, 1 toe = 39.68320 million Btu (EIA n.d.).
26. Total Factor Productivity (TFP): Is the productivity involving all the input factors to produce the output. Technical changes, scale, and technical efficiency are considered important components of TFP. In other words the TFP can be decomposed into measures of technical change, scale, and technical efficiency components (Lovell 1996).
27. Technical Changes: It is defined as a shift in the production function (Solow 1957), and hence, in the production frontier. If the technological change results in producing more output with the same given inputs, then the production is

said to be subjected to technical progress. On the other hand, if the technological change leads to lower the production given the same amount of inputs, then it is defined as being subjected to technical regress (Lovell 1996). The technical change can be decomposed into two components: Pure technical change which depends on only time, and non-neutral technical change, which is affected by changes in inputs over time (Kumbhakar et al. 2002).

28. Technical Efficiency (TEF): According to Koopmants (1951) definition, the technical efficiency is the firm' ability to minimize the level of inputs used for producing a given amount of output. Hence a firm's production said to be technically inefficient if it fails to maximize its output with the given inputs in production (Coelli and Battese 1998; Timmer 1971).
29. Total Factor Productivity Growth: It is defined as annual growth rate (for example in an output variable like GDP for a country or output for a firm over time). It comes from changes in technology and in inputs utilization. Changes in technology increase productivity for a given input and positive changes in specific input increases output (Sahu and Narayanan 2011). The TFP growth can be decomposed into several components. In the case of this study, it will be decomposed into two: Technical change and scale components. Technical change is the derivative of output with respect to time or to shift in the production function over time. The technical change has two components: Neutral, which depends on only time, and non-neutral, which depends on changes in the level of inputs. When time elapses and technology changes, the intensity in the use of inputs will change as well (like energy saving, or capital using). The scale component is due to deviation from the constant returns to scale RTS (if all inputs are increased by 1%, output increases by 1%). If the RTS is less than unity, TFP decreases, while it will increase if RTS is bigger than unity (Heshmati 1996).
30. Time Elasticity of Demand: It measures how changes in some factors such as technology lead to change in energy demand (Allen et al. 2009). Mathematically, it can expressed as follows:

$$E_t = \frac{\Delta E}{\Delta T} \cdot \frac{T}{E} = \frac{E_t/E_{t-1}}{T_t/T_{t-1}} \cdot \frac{T}{E} \quad (1.5)$$

31. Here in the absence of a true measure of technology, time represents un-specified technology, it is interpreted as rate of technical change. If positive, changes in technology increase the demand for energy, while if negative, changes in technology decrease the demand for energy. In general, technology development progresses postulate that technology is energy saving, meaning for the same level of output less energy is expected to be used in production, or alternatively for the same level of energy input more output is produced.

1.9 Expected Results

The expected results from this study are to provide the industrial sector's stakeholders and environmental and industrial policy makers with a flexible model that has the capacity to assess outcomes of different policies under certain scenarios.

Through the use of the developed models, the industrial sector's stakeholders and environmental and industrial policy makers will be able to identify the factors that affect the level of inputs used, output, and their effectiveness. Better policies and regulations are expected to be derived concerning investment in ICT capital, energy use, efficiency programs, and greenhouse gas emission issues.

1.10 The Structure of This Book

This book is organized into eight chapters. It is organized as a monograph consisting of chapters that are interrelated and sequentially developed into a final product.

Following this introductory chapter which provides a general overview of this sturdy, Chap. 2 will provide a brief history of the South Korean industrial sector and their development over time, focusing on the ICT investment and energy consumption, and sheds light on the energy intensity and the energy use efficiency programs.

Chapter 3 reviews the relevant literature about ICT investment and energy use pertaining to this study. It is divided into sections including ICT investment and the economic growth, and literature on energy demand and efficiency.

Chapter 4 reviews literature on the factor demand models and the theory of productivity along with presenting the relevant theories and existing researches related to the analysis of the productivity growth. It is divided into sections including historical review of developing the dynamic factor demand model, inter-factor substitutability and complementarity, and the TFP growth.

Chapter 5 deals with the data used for this study, it starts with a presentation of a descriptive statistics and population and sampling strategy. The classification of the industrial sector based on specific characteristics is also presented and discussed in detail. The chapter then analyzes the energy intensity based on the raw data.

Chapter 6 provides the methodology applied in this study. The general theoretical model is specified, and the first order conditions for the optimal input path are derived using the dynamic factor demand model under static expectation with infinite planning horizon. The algorithm for the estimation of the first model (effects of ICT investment on energy demand) is then presented.

Chapter 7 presents the econometric specification of the dynamic factor demand model, to measure and decompose the TFP, and compare with the conventional measures of the TFP growth. Various elasticities, measures of capacity utilization, returns to scale, and technical change effects are presented and discussed in this chapter.

Chapter 8 is the final chapter of this study. It identifies the major limitations of the previous studies, the contribution of the current study to the existing literature, and identifies the significance of the study. It then provides conclusion for this study, by summarizing the estimated models and discussing the relevant implications based on the estimated results. In addition, policy recommendations and suggestions for further and future research are proposed.

1.11 Summary

The overall consumption of energy worldwide is continuously increasing. The energy consumption will continue to increase worldwide by 48% in 2040. This increase in the energy demand will negatively affect the environment and the availability of depletable energy sources of fuel, or primary energy needed to produce energy output such as electricity.

Strong economic development leads to increase in the demand for energy in the industrial sector. The industrial sector consumes at least 37% of the total energy supply, which is relatively more energy intensive than any other major sectors including household, agriculture, and public services.

The increase in the demand for energy leads to increase in its price. This increase is attributed to increase in the demand for oil and in the production cost. Industrial policy decision makers need to understand the importance of the energy in the industrial production structure in order to assess and formulate necessary energy conservation measures. Efficient use of energy will reduce the energy intensity, which may contribute to reduction in the corresponding global emissions of air pollution and greenhouse gases.

This book addresses mainly four aspects of production and energy demand in manufacturing: First, it will establish a relationship between different factors of production. Second, it will investigate whether the energy demand in the industrial sector in South Korea can be decreased/increased by substituting/complementing with other input factors such as ICT capital and labor. Third, it will look at the sources of growth in the industrial sector through decomposing the Divisia index based TFP. Finally it provides appropriate policy recommendations based on the findings.

The expected result for this study is to provide the industrial sector's stakeholders and environmental and industrial policy makers with a flexible model that has the capacity to assess outcomes of various policies under certain scenarios.

Bibliography

Abdelaziz, E. A., Saidur, R., & Mekhilef, S. (2011). A review on energy saving strategies in industrial sector. Renewable & Sustainable Energy Reviews, *15*(1), 150–168. doi:10.1016/j.rser.2010.09.003

Allan, G., Hanley, N., McGregor, P., Swales, K., & Turner, K. (2007). The impact of increased efficiency in the industrial use of energy: A computable general equilibrium analysis for the United Kingdom. *Energy Economics, 29*(4), 779–798. doi:10.1016/j.eneco.2006.12.006

Allen, R. G. D. (1938). *Mathematical analysis for economists*. New York, USA: St. Martin's Press.

Allen, W. B., Weigelt, K., Doherty, N., & Mansfield, E. (2009). *Managerial economics: Theory, applications, and cases*. New York, USA: Norton.

Apostolakis, B. E. (1990). Energy-capital substitutability/complementarity. *Energy Economics, 12* (1), 48–58. doi:10.1016/0140-9883(90)90007-3

Arnberg, S., & Bjorner, T. B. (2007). Substitution between energy, capital and labour within industrial companies: A micro panel data analysis. *Resource and Energy Economics, 29*(2), 122–136. doi:10.1016/j.reseneeco.2006.01.001

Benjamin, D., & Meza, F. (2009). Total factor productivity and labor reallocation: The case of the Korean 1997 crisis. *B E Journal of Macroeconomics, 9*(1), 1–39. doi:10.2202/1935-1690.1625

Bernanke, B. S. (1983). Irreversibility, uncertainty, and cyclical investment. *The Quarterly Journal of Economics, 98*(1), 85–106. doi:10.2307/1885568

Berndt, E. R., & Wood, D. O. (1975). Technology, prices, and the derived demand for energy. *The Review of Economics and Statistics, 57*(3), 259–268.

Berndt, E. R., & Wood, D. O. (1979). Engineering and econometric interpretations of energy-capital complementarity. *American Economic Review, 69*(3), 342–354.

Cardona, M., Kretschmer, T., & Strobel, T. (2013). ICT and productivity: Conclusions from the empirical literature. *Information Economics and Policy, 25*(3), 109–125.

Cho, W. G., Nam, K., & Pagan, J. A. (2004). Economic growth and interfactor/interfuel substitution in Korea. *Energy Economics, 26*(1), 31–50. doi:10.1016/j.eneco.2003.04.001

Christensen, L. R., Jorgenson, D. W., & Lau, L. J. (1973). Transcendental logarithmic production frontiers. *Review of Economics and Statistics, 55*(1), 28–45. doi:10.2307/1927992

Coelli, T., & Battese, R. D. G. (1998). *An introduction to efficiency and productivity analysis*. London, England: Kluwer Academic Publisher.

Collard, F., Feve, P., & Portier, F. (2005). Electricity consumption and ICT in the French service sector. *Energy Economics, 27*(3), 541–550. doi:10.1016/j.eneco.2004.12.002

Dale, A., Wathan, J., & Higgins, V. (2008). Secondary analysis of quantitative data sources. In P. Alasuutari, L. Bickman, & J. Brannen (Eds.), *The Sage handbook of social research methods* (pp. 520–535). USA: Sage.

Dargay, J. M. (1983). The demand for energy in Swedish manufacturing-industries. *Scandinavian Journal of Economics, 85*(1), 37–51. doi:10.2307/3439909

Dietmair, A., & Verl, A. (2009). A generic energy consumption model for decision making and energy efficiency optimisation in manufacturing. *International Journal of Sustainable Engineering, 2*(2), 123–133. doi:10.1080/19397030902947041

Dimitropoulos, J. (2007). Energy productivity improvements and the rebound effect: An overview of the state of knowledge. *Energy Policy, 35*(12), 6354–6363. doi:10.1016/j.enpol.2007.07.028

EIA. (2011, February 26, 2013). *International energy outlook. US energy information administration*. US Energy Information Administration. Retrieved from http://www.eia.gov/forecasts/ieo/pdf/0484(2011).pdf

EIA. (2013, February 26, 2013). *International energy statistics-units.* US Energy Information Administration. Retrieved from http://www.eia.gov/cfapps/ipdbproject/docs/unitswithpetro.cfm

EIA. (2016, September 27, 2016). *International energy outlook 2016. With projection to 2040*. Retrieved from https://www.eia.gov/forecasts/ieo/world.cfm

EIA. (n.d.). *International energy statistics-units*. US Energy Information Administration. Retrieved from EIA website: http://www.eia.gov/cfapps/ipdbproject/docs/unitswithpetro.cfm

EPA. (2007, February, 12, 2013). *Energy trends in selected manufacturing sectors: Opportunities and challenges for environmentally preferable energy outcomes*. Environmental Protection Agency. Retrieved from http://www.epa.gov/sectors/pdf/energy/report.pdf

Favennec, J. P. (2005). Oil and natural gas supply for Europe. *Catalysis Today, 106*(1–4), 2–9. doi:10.1016/j.cattod.2005.07.171

Field, B. C., & Grebenstein, C. (1980). Capital-energy substitution in US manufacturing. *The Review of Economics and Statistics, 62*(2), 207. doi:10.2307/1924746

Finley, M. (2012). The oil market to 2030: Implications for investment and policy. *Economics of Energy and Environmental Policy, 1*(1), 25–36.

Fleiter, T., Worrell, E., & Eichhammer, W. (2011). Barriers to energy efficiency in industrial bottom-up energy demand models—A review. *Renewable and Sustainable Energy Reviews, 15* (6), 3099–3111.

Friedemann, M., Staake, T., & Weiss, M. (2010). *ICT for Green: How computers can help us to conserve energy.* Paper presented at the Proceedings of the 1st International Conference on Energy-Efficient Computing and Networking. Passau, Germany.

Frondel, M., & Schmidt, C. M. (2002). The capital-energy controversy: An artifact of cost shares? *Energy, 23*(3), 53–79.

Fukao, K., Miyagawa, T., & Pyo, H. K. (2009, May, 18, 2013). *Estimates of multifactor productivity, ICT contributions and resource reallocation effects in Japan and Korea* (RIETI Working Paper 09-E-021). The Research Institute of Economy, Trade and Industry. RIETI Discussion Paper Series. Retrieved from http://www.rieti.go.jp/jp/publications/dp/09e021.pdf

Ge, M., Friedrich, J., & Damassa, T. (2014). *(6) Graphs explain the world's top 10 emitters*. World Resources Institute. Retrieved from http://www.wri.org/blog/2014/11/6-graphs-explain-world %E2

Griffin, J. M., & Gregory, P. R. (1976). An intercountry translog model of energy substitution responses. *The American Economic Review, 66*(5), 845–857. doi:10.2307/1827496

Grosskopf, S. (1993). *Efficiency and productivity* (pp. 160–194). The measurement of productive efficiency: Techniques and applications.

Henry, C. (1974). Investment decisions under uncertainty: the "irreversibility effect". *The American Economic Review, 64*(6), 1006–1012.

Heshmati, A. (1996). On the single and multiple time trends representation of technical change. *Applied Economics Letters, 3*(8), 495–499. doi:10.1080/135048596356104

Heshmati, A. (2003). Productivity growth, efficiency and outsourcing in manufacturing and service industries. *Journal of Economic Surveys, 17*(1), 79–112. doi:10.1111/1467-6419.00189

Heshmati, A. (2013). Demand, customer base-line and demand response in the electricity market: A survey. *Journal of Economic Surveys*, n/a-n/a. doi:10.1111/joes.12033

Imran, K., & Siddiqui, M. M. (2010). Energy consumption and economic growth: A case study of three SAARC countries. *European Journal of Social Sciences, 16*(2), 206–213.

Jaeger, P. T. (2003). The endless wire: E-government as global phenomenon. *Government Information Quarterly, 20*(4), 323–331. doi:10.1016/j.giq.2003.08.003

Johnson, B. (2001). Toward a new classification of nonexperimental quantitative research. *Educational Researcher, 30*(2), 3–13.

Jorgenson, D. W., & Stiroh, K. J. (1999). Information technology and growth. *American Economic Review, 89*(2), 109–115. doi:10.1257/aer.89.2.109

Kander, A., & Schön, L. (2007). The energy-capital relation—Sweden 1870–2000. *Structural Change and Economic Dynamics, 18*(3), 291–305. doi:10.1016/j.strueco.2007.02.002

Khayyat, N. T. (2013). *Exploring demand for energy in the South Korean industries* (Doctoral dissertation), SMC University, Zurich, Switzerland. Retrieved from http://www.smcuniversity.com/item/exploring-demand-for-energy-in-the-south-korean-industries.html

Khayyat, N. T. (2015). *Energy demand in industry: What factors are important? Dordrecht*. Netherlands: Springer.

Kim, B. C., & Labys, W. C. (1988). Application of the translog model of energy substitution to developing-countries—The case of Korea. *Energy Economics, 10*(4), 313–323. doi:10.1016/0140-9883(88)90043-6

Knut, S., & Hammond, P. (1995). *Mathematics for economic analysis*. Prentice Hall.

Koetse, M. J., de Groot, H. L. F., & Florax, R. J. G. M. (2008). Capital-energy substitution and shifts in factor demand: A meta-analysis. *Energy Economics, 30*(5), 2236–2251. doi:10.1016/j.eneco.2007.06.006

Koopmants, T. C. (1951). An analysis of production as an efficient combination of activities. In T. C. Koopmants (Ed.), *Activity analysis of production and allocation* (pp. 33–97). New York, USA: Wiley.

Kuemmel, R., Stresin, R., Lindenberger, D., & Journal, B. (2008). Co-integration of output, capital, labor and energy. *The European Physical, 66*(2), 279–287.

Kumbhakar, S. C., Heshmati, A., & Hjalmarsson, L. (1997). Temporal patterns of technical efficiency: Results from competing models. *International Journal of Industrial Organization, 15*(5), 597–616. doi:10.1016/S0167-7187(96)01053-3

Kumbhakar, S. C., Hjalmarsson, L., & Heshmati, A. (2002). How fast do banks adjust? A dynamic model of labour-use with an application to Swedish banks. *Journal of Productivity Analysis, 18*(1), 79–102.

Kumbhakar, S. C., & Lovell, C. A. K. (2000). *Stochastic frontier analysis*. Cambridge: UK.

Laitner, J. A. (2002). Information technology and US Energy consumption: Energy hog, productivity tool, or both?. *Journal of Industrial Ecology, 6*(2), 13–24. doi:10.1162/108819802763471753

Lomax, R. G. (2007). *Statistical concepts: A second course for education and the behavioral sciences* (3rd ed.). Mahwah, NJ: Lawrence Erlbaum Associates.

Lovell, C. A. K. (1996). Applying efficiency measurement techniques to the measurement of productivity change. *Journal of Productivity Analysis, 7*(2–3), 329–340.

Ma, H., Oxley, L., Gibson, J., & Kim, B. (2008). China's energy economy: Technical change, factor demand and interfactor/interfuel substitution. *Energy Economics, 30*(5), 2167–2183.

Melville, N. P. (2010). Information systems innovation for environmental sustainability. *MIS Quarterly, 34*(1), 1–21.

Mukherjee, K. (2008). Energy use efficiency in US manufacturing: A nonparametric analysis. *Energy Economics, 30*(1), 76–96. doi:10.1016/j.eneco.2006.11.004

O'Mahony, M., & Timmer, M. P. (2009). Output, input and productivity measures at the industry level: The EU KLEMS database. *The Economic Journal, 119*(538), F374-F403. doi:10.1111/j.1468-0297.2009.02280.x

O'brien, R. M. (2007). A caution regarding rules of thumb for variance inflation factors. *Quality & Quantity, 41*(5), 673–690. doi:10.1007/s11135-006-9018-6

Park, C., Kwon, K., Kim, W., Min, B., Park, S., Sung, I., Seok, J. (2009). Energy consumption reduction technology in manufacturing—A selective review of policies, standards, and research. *International Journal of Precision Engineering and Manufacturing, 10*(5), 151–173. doi:10.1007/s12541-009-0107-z

Pindyck, R. S. (1979). Interfuel substitution and the industrial demand for energy: An international comparison. *The Review of Economics and Statistics, 61*(2), 169–179.

Romm, J. (2002). The internet and the new energy economy. *Resources, Conservation and Recycling, 36*(3), 197–210. doi:10.1016/S0921-3449(02)00084-8

Sahu, S. K., & Narayanan, K. (2011). Total factor productivity and energy intensity in Indian manufacturing : A cross-sectional study. *International Journal of Energy Economics and Policy, 1*(2 SRC—Google Scholar), 47–58.

Saicheua, S. (1987). Input substitution in Thailand's manufacturing sector: Implications for energy policy. *Energy Economics, 9*(1), 55–63.

Schulte, P., Welsch, H., & Rexhäuser, S. (2014). ICT and the demand for energy: Evidence from OECD Countries. *Environmental and Resource Economics,* 1–28. doi:10.1007/s10640-014-9844-2

Solow, R. M. (1957). Technical change and the aggregate production function. *Review of Economics and Statistics, 39*(3), 312–320. doi:10.2307/1926047

Soytas, U., & Sari, R. (2009). Energy consumption, economic growth, and carbon emissions: Challenges faced by an EU candidate member. *Ecological Economics, 68*(6), 1667–1675. doi:10.1016/j.ecolecon.2007.06.014

Stern, D. I. (2011). The role of energy in economic growth. *Annals of the New York Academy of Sciences, 1219*(1), 26–51. doi:10.1111/j.1749-6632.2010.05921.x

Strassmann, W. P. (1959). Interrelated industries and the rate of technological-change. *Review of Economic Studies, 27*(72–77), 16–22. doi:10.2307/2296047

Terrados, J., Almonacid, G., & Hontoria, L. (2007). Regional energy planning through SWOT analysis and strategic planning tools: Impacts on renewable development. *Renewable and Sustainable Energy Reviews, 11*(1), 1275–1287.

Thompson, P., & Taylor, T. G. (1995). The capital-energy substitutability debate: A new look. *The Review of Economics and Statistics, 77*(3), 565–569. doi:10.2307/2109916

Timmer, C. P. (1971). Using a probabilistic frontier production function to measure technical efficiency. *Journal of Political Economy, 79*(4), 776–794. doi:10.1086/259787

Vu, K. M. (2011). ICT as a source of economic growth in the information age: Empirical evidence from the 1996–2005 period. *Telecommunications Policy, 35*(4), 357–372.

Welsch, H., & Ochsen, C. (2005). The determinants of aggregate energy use in West Germany: Factor substitution, technological change, and trade. *Energy Economics, 27*(1), 93–111. doi:10.1016/j.eneco.2004.11.004

Wheeler, D., & Tiefelsdorf, M. (2005). Multicollinearity and correlation among local regression coefficients in geographically weighted regression. *Journal of Geographical Systems, 7*(2), 161–187. doi:10.1007/s10109-005-0155-6

Wooldridge, J. M. (2006). *Introductory econometrics: A modern approach* (4th ed.): Michigan State University.

Zahan, M., & Kenett, R. S. (2013). Modeling and forecasting energy consumption in the manufacturing industry in South Asia. *International Journal of Energy Economics and Policy, 2*(1), 87–98.

Zeadally, S., Khan, S., & Chilamkurti, N. (2012). Energy-efficient networking: Past, present, and future. *Journal of Supercomputing, 62*(3), 1093–1118. doi:10.1007/s11227-011-0632-2