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Investigating the Relationship between ICT Investment and Energy Use and its Impact on Productivity

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Investigating the Relationship between ICT Investment and Energy use and its impact on Productivity

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Abstract

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The overall consumption of energy worldwide is continuously increasing. According to the International Energy Outlook Report published in 2011 by the U.S. Energy Information Administration (EIA), energy consumption will increase worldwide by 53% in 2035. 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. South Korea imports all its primary energy leading to high dependency and vulnerability related to the energy supply. This quantitative research study investigates the impact that different input factors of production have on the market, as well as consumer and producer characteristics on energy demand in 30 industrial sectors for South Korea over the period 1980–2009, with a special emphasis on the effects of Information and Communication Technology (ICT) investment on the demand for energy. A dynamic factor demand model is applied to link inter-temporal production decisions by explicitly recognizing that the level of certain factors of production cannot be changed without incurring some costs, so called "adjustment costs", and are defined in terms of forgone output from current production. The objective is to examine the structure of factors affecting productivity in these industries. In particular, the focus is on the ICT-energy relationship and their effects on the total factor productivity (TFP) growth. The results are expected to reveal the state of productivity in each individual industry, which is an important basic knowledge for policy makers in designing industrial policy and allocating public investment and supports. The results of this study are expected to give useful information to policy makers who attempt to promote productivity in the industries covered and at the national level. The findings reveal that ICT and non-ICT capital investments are substitutes for labor and energy inputs. There is a significant contribution of ICT capital in both output and labor productivity growth when considering the rate of ICT capital in the capital-investment ratio. The results demonstrate a high output growth rate and increasing returns to scale, in which its effects are higher than technological progress in the TFP component. Future studies will need to decompose the aggregated figures of the energy input by the different types of energy in order to evaluate their individual effects on industrial production, specify the substitution effects more precisely, and to consider the direct ICT effects on energy conservation more effectively.

Keywords: Dynamic Factor Demand; Panel Data; ICT Investment; Energy Demand; Adjustment Speed; Total Factor Productivity.

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Chapter 1: Overview

This dissertation deals with an econometric specification and the estimation of a dynamic factor demand model. This chapter introduces to the reader a general overview of this dissertation. It starts with an introduction related to energy demand and consumption worldwide, and then explicitly states the problem and purpose of the research.

1.1 Introduction

The overall consumption of energy worldwide is continuously increasing. According to the International Energy Outlook Report published in 2011 by the US Energy Information Administration (EIA), the energy consumption will increase worldwide by 53% in 2035. In 2008 the total energy consumption was 505 quadrillion Btu (British thermal unit). It is expected to reach 770 Btu by the year 2035 (EIA, 2011). 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 period 2008-2035 is shown in Table 1.1 (the 2008 numbers are actual energy demand). 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.

Table 1. 1

World Estimated Energy Demand 2008-2035 (in Quadrillion Btu [1])

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	126.1	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)

Strong economic development leads to an increase in the demand for energy in the industrial sector. The industrial sectors 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, Saidur, & Mekhilef, 2011; Friedemann, Staake, & Weiss, 2010). A study conducted by the US Environmental Protection Agency (EPA) in 2007 revealed that 30% of the energy consumed by industrial and

[1] 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, 2013b).

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).

This quantitative research study investigates the impact that different input factors of production have on the market, as well as 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, Hanley, McGregor, Swales, & Turner, 2007; Mukherjee, 2008). The TFP growth is estimated parametrically and decomposed into different components.

This dissertation 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 between factors of production, and can generate interpretation problems. 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 decomposed into four different components: technical change effect, scale effect, temporary equilibrium effect, and direct adjustment cost effect.

1.2 Problem Statement

The steady increase in the demand for energy leads to an increase in energy prices. According to EIA (2011), the crude oil price will average 100 USD per barrel for the next twenty years, but will reach more than 200 USD per barrel in 2030. This increase in energy price, according to the report, is due to an increase in the demand for oil and in the production cost. 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, de Groot, & Florax, 2008).

In the last twenty years, 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). The importance of the rapid substitution toward ICT for other factors is due to the rapid decline in the ICT price, as emphasized by Jorgenson and Stiroh (1999) due to induce in the rapid decline in 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. 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 & Sari, 2009; Stern, 2011). The energy sector is undergoing reforms aimed at using more advanced technology in the generation, transmission, and distribution stages (Fukao, Miyagawa, & Pyo, 2009). The aim 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 those 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, Feve, and Portier (2005), the net effect of ICT diffusion may be more difficult to evaluate given the uncertainty of its consequences on productive and social structures. 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 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). This quantitative research 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 Purpose of Research

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. The intensity of energy use in the modern production technology is a critical issue, as the modern production technology is often using energy in an intensive way (Stern, 2011; Zahan & Kenett, 2013).

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

The objective of this quantitative research is to examine the different input factors in the production process for the South Korean industrial sector and compare 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. The elasticity of input factors and output are studied. Structural changes in various input demand patterns are explored for different periods and decades. In addition, this study aims to determine 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 (Arnberg & Bjorner, 2007; Kander & Schön, 2007; Koetse et al., 2008; Ma, Oxley, Gibson, & Kim, 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 the growth.

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

1.4 Dissertation Organization

This dissertation is organized into seven 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 research, Chapter two describes the structure of this study, the research questions and the related hypotheses, assumptions and limitations. It then provides a brief history of the industrial sectors and their development over time, focusing on the ICT investment and energy consumption in South Korea, and sheds light on the energy intensity and the energy use efficiency programs. It then provides a summary of expected results.

Chapter three reviews the relevant literature pertaining to this dissertation. It is divided into sections including historical review of developing the dynamic factor demand model, inter-factor substitutability and complementarity, ICT investment and the economic growth, the TFP growth, literature on energy demand and efficiency, as well as identifying the major limitations of the previous studies, the contribution of the current study to the existing literature, and finally identifies the significance of the study.

Chapter four 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 along with validating of results and multicollinearity issues.

Chapter five provides the methodology applied in this dissertation. The general theoretical model is specified, and the first order conditions for the optimal input path are derived using 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 six 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 seven is the final chapter of this dissertation. It 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.

Chapter 2: Structure of the Research

This chapter presents the organizational structure of this study, followed by research questions and related hypotheses to be tested. It will then discuss the major limitations and stated assumptions. Finally it provides a brief history of the economic development of South Korea with related energy demand and ICT investment.

2.1 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 branch of literature that constructs the relationship between energy consumption or demand with other input factors of production, (see for example: Apostolakis, 1990; Dietmair & Verl, 2009; Field & Grebenstein, 1980; Frondel & Schmidt, 2002; Imran & Siddiqui, 2010; Kuemmel, Stresin, Lindenberger, & Journal, 2008; C. Park et al., 2009; Pindyck, 1979; Zahan & Kenett, 2013).

The review of relevant literature, as well as other studies analogous to studies by the authors quoted above, on production functions (Berndt & Wood, 1975, 1979; Christensen, Jorgenson, & Lau, 1973; Griffin & 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 production functions.

Accordingly, this dissertation employs the knowledge gained 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 over the period 1980–2009.

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 require more time and an expensive planning process in addition to data mining and documenting (Dale, Wathan, & Higgins, 2008). The panel data was collected from different Microsoft Excel spreadsheets mainly provided by the Asia KLEMS growth and productivity account database. The data was then complied into a single spreadsheet for the initial statistical analysis (descriptive statistics). Finally, a detailed analysis using SAS code 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.

2.2 Research Questions and Hypotheses

This study addresses three research questions with respect to the production technology and the nature of the productivity growth in the South Korean industrial sectors. The research questions can be stated as follows:

1. What is the relationship between the ICT capital investment and energy use in the production process of the South Koran 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 Koran 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 corresponding hypothesis for research question 1 is as follows:

Hypothesis 1: The ICT capital investment and energy use have a substitutable relationship in the production process of the South Korean industrial sectors.

The corresponding hypotheses for research question 2 are:

Hypothesis 2: The level of ICT investment is lower than the optimal value in the production process of the South Korean industrial sectors.

Hypothesis 3: The level of energy use is higher than the optimal value in the production process of the South Korean industrial sectors.

The corresponding hypotheses for research question 3 are:

Hypothesis 4: The static equilibrium model is unable to describe the technology and structure of the factor demand of the industrial sectors in South Korea due to the presence of a dynamic adjustment cost for the quasi-fixed input factors of production.

Hypothesis 5: The South Korean industrial sectors exhibit constant returns to scale.

For research question 4, the hypothesis is:

Hypothesis 6: Technical change 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 sectors when it comes to industry heterogeneity and stochastic shocks, such as an oil shock or financial crisis (Benjamin & Meza, 2009; Khayyat, 2013). Further motivation is due to the continuous debate over 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; P. Thompson & Taylor, 1995; Welsch & Ochsen, 2005).

These hypotheses 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 sector can be exploited for the purpose of policy analysis.

2.3 Assumptions and Limitations

This section outlines the following types of assumptions made in completion of this dissertation study: Methodological 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.

2.3.1 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 like 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 (W. G. Cho, Nam, & Pagan, 2004; Khayyat, 2013; B. C. Kim & Labys, 1988).

2.3.2 Methodological and theoretical assumptions

Some specific assumptions are needed in order to formulate the production and factor demand models for this dissertation. The explanatory variables used to formulate the production function 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, services, energy, and ICT capital).

In this dissertation 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.

2.4 Expected Results

The expected result for this dissertation 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.

Through the use of the developed models, they 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.

2.5 History of Economic Development in South Korea

South Korea is a new industrialized economy that has taken advantage of technological development, thereby serving as an economic model for emerging economies. It enjoyed a high economic growth rate from the post-war period until 1997, in which its per capita GDP was 10,000 USD. The Korean economy has quickly recovered from the Asian Financial Crisis of the late 1990s, the ICT bubble of 2001, and the credit crunch of 2003 (Borensztein & Lee, 2000; D. Oh, Heshmati, & Lööf, 2012).

South Korea was the first country to recover within a year from the Global Economic Crisis of 2007/08. In addition, through the conclusion of negotiations on a US–South Korea free trade agreement (FTA), and a potential Japan–South Korea FTA in the future, the liberalization of South Korean markets will continue (Fukao, Miyagawa, & Pyo, 2009).

In contract, Japan has suffered from an economic recession since the 1990s although the government has adopted different macroeconomic policies in order to stimulate the economy, and promoted deregulation and restructuring of industries (EIA, 2013a). However, Japan is still considered as the world's fourth largest energy consumer.

The primary energy composition of Korea and Japan is similar, a half of their consumption comes from petroleum. Due to lack of domestic energy resources, both countries are promoting nuclear energy as a national policy (Kanagawa & Nakata, 2006).

2.5.1 Stages in the industrial and technological polices

The South Korean government has applied a sequence of industrial and technological policy initiatives across different stages of its economic development, in which it assisted in interpreting most of the economic variables estimated under this study. A brief history of the policy initiatives is provided bellow based on literature survey conducted by S. T. Kim (1997), I. Oh, Heshmati, Baek, and Lee (2009), and P. Park (2000):

The growth of the 1960s development stage period was an input driven growth with cheap labor, and characterized by forming the economic development plan, and export oriented for light industries such as bicycle and textile. For the technology policy, the government concentration was on the creation of the key organizations and institutional arrangements through government entities such as the Ministry of science and technology, and science and technology promotion Act, as well as technology absorption.

For the period of the 1970s, the policy shifted from the input driven to the investment driven growth, represented by production capability. The industrial policy was concentrated on heavy and chemical industries. For the technology policy the research and educational structure represented by public research institutions and science and techno parks. The industry policy of this period was characterized by technology absorption.

For the period of the 1980s onward, the policy focused on the growth in foreign direct investment (FDI), concentrating on technology based industries as a source of economic growth. The technology policy was toward encouraging the private sector for innovativeness and research and development (R&D), also called for collaboration between the ministries' R&D activities.

The period of the 1990s saw continuously supported FDI with concentration in technology as a source of economic growth, and enhancing the innovation capabilities in the private sector. Therefore, hi-tech sectors were encouraged to internationalize. This period was characterized by highly advanced technology area, ICT, Bio-technology and R&D collaboration.

The globalization era in the 2000s was the last stage of the process of economic growth in South Korea, where the growth was mainly from technology and innovation, and building the national innovation system.

The above mentioned policies reveal the redirection of the focus of South Korean industrial plan strategy from a consumer oriented industry, to a heavy and chemical industry, and then to a technology intensive industry. The government's intervention has changed from direct and sector-specific involvement to indirect, sector-neutral functional support system. The mission of technology policy also has been adjusted from absorption of foreign technologies to the creation of new ones. All these changes in policy initiatives were responses to the growth of the technology capability of the private sector, and the changing international economic conditions, which turned out to be quite successful.

2.5.2 Energy efficiency program

The energy demand management or the so-called demand side management (DSM) is implemented in South Korea, targeting the energy sectors of electricity, gas, and heating. The Korea Electric Power Corporation (KEPCO) is responsible for the load management program and efficiency, and for the Variable Speed Drive (VSD) program, which aims at implementing high efficiency lighting. As part of the program, transformers are implemented and managed by the government (W. N. Lee, Kim, Park, Roh, & Cho, 2012).

The South Korean annual energy consumption growth reached 4.9% in year 2009. The per capita consumption of energy in South Korea is about (5.0) toe in 2009 [2], in which it accounted for more than twice of the world's average energy consumption. Major energy sources include fuel oil, coal, nuclear energy, and Liquid Natural Gas (LNG). Although an increase in the use of renewable energy is expected, it will not contribute to the remarkable energy supply in the South Korean energy systems. This poor self-sufficiency is one of the most critical components of the national energy system that leaves South Korea vulnerable to future energy shocks. In this light, the stable energy supply and conservation is vital to the nation's sustainable development (W. N. Lee et al., 2012).

Japan, in the other hand, keeps the steady increase in CO2 gas emission. The Japanese government ratified the Kyoto Protocol, and accordingly is required to reduce its CO2 gas emission on annual basis. Despite the government proposed several national actions for the reduction,

[2] 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, 2013b).

Japan is unlikely to achieve its emission target by itself, and is developing applications of the Kyoto Mechanisms such as the Joint Implementation and the Clean Development Mechanism (Kanagawa & Nakata, 2006).

Different energy conservation programs have been promoted by South Korean government. For example, tax breaks, loan and subsidy programs, energy conservation technologies, various pilot projects, energy exhibition, and energy service companies program. An efficient use of energy is not only beneficial to the nation's economy but also important for conservation of natural environment. The major share of this high rate of consumption in energy comes from the electricity, as its share from the final energy consumption has doubled from 12% to 23% by the year 2009 compared with a decade ago. In the industrial sector, the electricity share of the annual final energy consumption growth has reached more than 5.8% (International Energy Agency IEA, 2011).

The South Korean government has developed a set of five-year plan for rational utilization of energy since 1993. Hereafter, a basic national energy plan 2008–2030 was announced in an attempt to reduce the energy use intensity by the end of 2030, with up to (38.0) million toe, which corresponds to 46% of the actual energy consumed. Within the frame of the energy plan, the South Korean industrial sector will have to reduce its energy consumption as minimum as 44% (IEA, 2009, 2011).

The rapid industrial development of South Korea in the twentieth century transformed its economy to a service based economy with an annual GDP growth of 2.9%. The electricity consumption share of total consumption of energy is rapidly growing. For example, the steel production is heavily depending on the electricity arc furnaces and accounted for nearly 57% in 2009. The chemical sector is the largest energy consumer in the South Korean industrial sectors, while the largest share of fuel mix in the industrial sectors is represented by liquid fuel consumption for feedstock use (IEA, 2011).

Figure 2.1 shows the development of energy use in the South Korean industrial sectors for the years 1980–2010. The figures are based on the aggregate level of energy used in the industrial sectors.

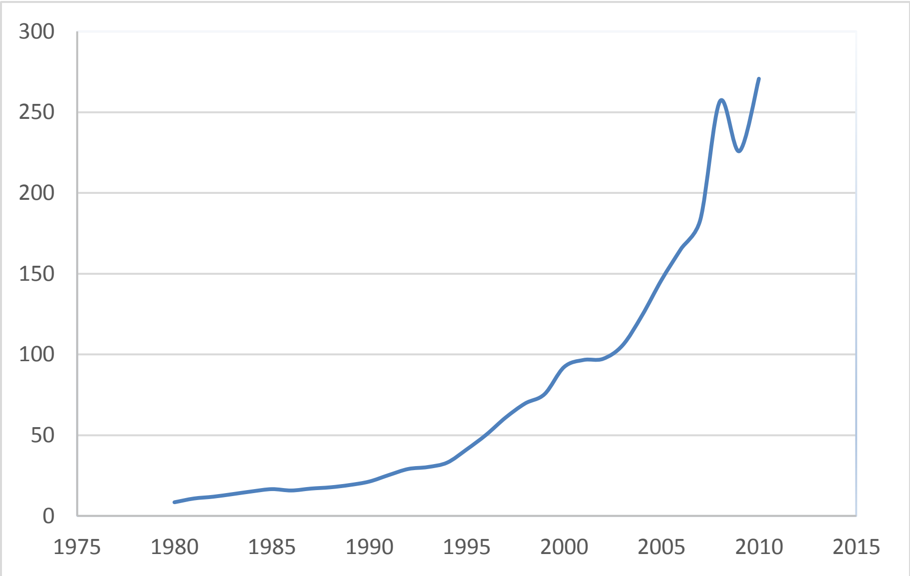


Figure 2. 1: *Total Industry Energy Consumption in South Korea (in millions of USD), 1980–2010*

2.5.3 ICT investment

The ICT industry has grown rapidly during the last decade. According to the Organization for Economic Cooperation and Development (OECD), South

Korea’s trade surplus in the ICT sector is about 43.30 billion USD, which makes it the largest net exporter of ICT among the OECD member countries.

In 2007, South Korea has exported ICT goods that valued at 97.40 billion USD, while importing ICT products worth of 54.10 billion USD. On average, the trade surplus of the South Korean ICT sector has been growing by approximately 10% a year from 1996 to 2007 (OECD, 2013). Many studies have explored the causes of this rapid growth in the South Korea’s ICT industry (See for example: J. Hwang & Lee, 2010; O. Y. Kwon & Shepherd, 2001; S. Lee, Kim, & Park, 2009; Shin & Park, 2007).

The success in the development of the ICT sector and infrastructure could partly be attributed to policies and initiatives of South Korea that developed before and after the 1997 Economic Crisis. Since the mid-1990s, the South Korean government has established three master plans for the development of the information society: (1) the Informatization Promotion Act (1995) followed by the First Master Plan for Informatization Promotion (1996), (2) Cyber Korea 21(1998) and (3) e-Korea Vision 2007.

South Korea came one step closer to a knowledge-based society with the construction of an advanced information infrastructure, the introduction of various information systems in public services and in the private sector, as well as growth in the overall ICT industry (I. D. R. C., 2008).

The development of ICT use in the South Korean industrial sectors for the years 1980–2010 is shown in Figure 2.2. The figures are based on the aggregate level of ICT capital investment in the industrial sector.

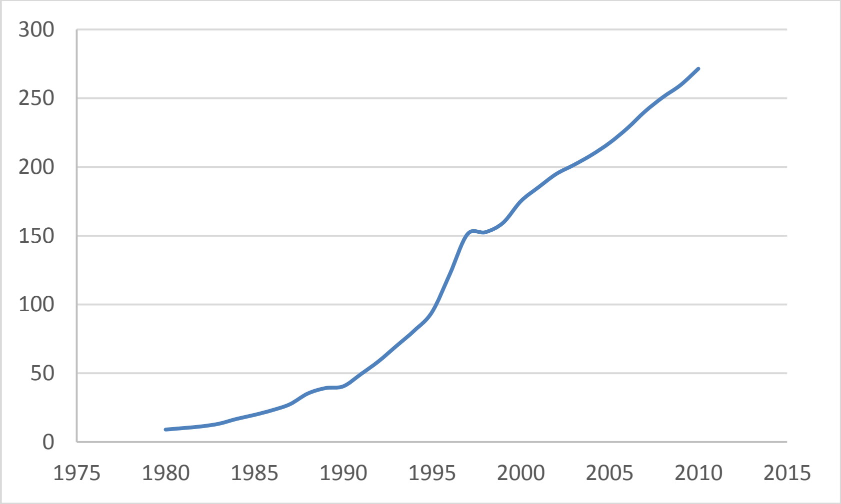


Figure 2. 2: *Total Industry ICT Investment in South Korea (in millions of USD), 1980–2010*

The average annual growth rate of ICT investment was 12.8% for the period 1980–2009. Although the ICT investment showed steady growth until 1997, but dramatically decreased during 1998 due to the Asian Financial Crisis. However it has recovered rapidly to reach 27 trillion KW in 2010. The share of ICT investment in total investment was 13% in 2010. The average share of ICT capital service in the total value added is 6.6% during 1980–2009. These figures indicate that South Korea has achieved considerable development in its economy from the share of ICT investment.

2.6 Summary

Energy is one of the critical driving forces for human life. It provides heat, light, mobility, etc. South Korea’s annual energy consumption growth reached 4.9% in the year 2009. The per capita consumption of energy in South Korea was about (5.0) toe in 2009, which accounted for more than twice of the world average.

South Korea imports more than 97% of its primary energy. Major energy sources include fuel oil, coal, nuclear energy, and LNG. Although an increase in the use of renewable energy is expected, it will not make a remarkable contribution to the energy supply in the South Korean energy systems. This lack of self-sufficiency is one of the most critical components of the national energy system that leave South Korea vulnerable to future energy shocks. In this light, the stable energy supply and conservation is vital to the nation's sustainable development.

South Korea has adopted a series of industrial and technological policy initiatives across different stages of economic development. Its economic development started in the 1960s, forming a set of five-year economic plans that concluded with the globalization in 2000s, in which technology, innovation, and building the national innovation system were the main pillars of its development.

The rapid industrialization and urbanization have resulted in a noticeable increase in the demand for energy, especially in the industrial sector. Although the policy of demand side management has been adopted in

South Korea with targeted energy sectors, South Korea’s annual energy consumption growth reached 4.9% in year 2009

Chapter 3: Literature Review

This chapter presents the theoretical foundation of this dissertation. It clearly outlines the background of the problem, along with presenting the relevant theories and existing researches related to the analysis of the productivity growth. The literature review for this dissertation study is mainly originated from academic research databases such as EconList, Science Direct, the Information Bridge: Department of Energy Scientific and Technical Information database and JSTOR, as well as Google scholar database. Seminal works from pioneers of major theories and concepts are also included.

The theoretical foundations of this dissertation study amount to more than 200 reviews of books, peer reviewed journal articles, institutional and annual reports, dissertations, and several websites. The three subtopic areas: Production function, dynamic factor demand, and productivity growth accounting were researched to conduct a comprehensive literature search on the dissertation topic: *Investigating the Relationship between ICT Investment and Energy Use and its Impact on Productivity.*

3.1 Summary of Previous Literature

3.1.1 Historical development of the factor demand models

The development of the factor demand models will be explained in this section within the framework of the theory of the firm's optimal input decisions in a non-static context. In doing so, the necessary related concepts will be explained in details as follows:

a. The firm's temporary equilibrium

The temporary equilibrium is a term originated from the Marshallian distinction between short- and long-run. It relies on the distinction between production possibilities that are immediately feasible and those that are only eventually feasible (Varian, 1992). Accordingly it is possible to classify the firm's input factors of production in the short-run into two categories: Variable inputs and quasi-fixed inputs.

For different reasons such as institutional factors or regulatory constraints and rationing schemes, and technological and market reasons, the quasi-fixed inputs cannot be rapidly adjusted to their optimal levels and it is often costly to adjust. When however this process is successfully undertaken, apparently after some times have passed, all inputs will be at their optimal levels.

This situation is often referred to as firm's long-run equilibrium. When the firm employs the cost minimizing amount of variable inputs (those inputs that can be freely changed in the short-run) for given levels of the remaining inputs (quasi-fixed factors), the firm is said to be in temporary equilibrium (Galeotti, 1990, 1996).

When time does not play an explicit role in the analysis, the study of the firm's decisions will account for the short/long-run distinction through the use of the so-called restricted technologies. The advantages of the temporary equilibrium analysis is that it provides sufficient information if concentrate the attention on the short-run production structure of the firm, and to study its restricted technology. If the appropriate regularity conditions are held, it is possible to obtain all the qualitative and quantitative information about the long-run (Galeotti, 1996).

b. The adjustment cost

Studies on production are often divided into the cost function (dual approach) studies, and technology flow (primal approach) studies. The dual approach studies rely on four concepts: First, the neoclassical theory of investment, second, the duality theory, third, the advances in flexible functional forms, and finally the various developments in the inter-temporal modeling of adjustment costs (Nadiri & Prucha, 1999).

The neoclassical theory of investment was mainly studied by Jorgenson (1963) who introduced the concept of user cost of capital, and refined the idea of lagged response of investment to the changes in capital demand. Nadiri and Rosen (1969) incorporated these ideas to a formal model where disequilibrium on one factor market may have consequences on others (Rouvinen, 1999).

The foundations of the duality theory in economics is laid by Shephard (1953). Flexible functional forms were introduced in economics to avoid restrictive features, for example Cobb-Douglas production function and Leontief production function specifications (Galeotti, 1990). Leontief production function is generalized by Diewert (1971), while Christensen et al. (1973) introduced transcendental logarithmic functional forms (Translog). Dual presentations of production functions, i.e., profit or cost functions have been popular in econometric modeling from early 1970s, since explicit derivation of demand systems from production possibilities was possible to be avoided (McFadden, 1978).

While inputs such as energy and materials are more likely considered as variable input factors of production, their use is often depend on the amounts of capital equipment and structures that are fixed in the short-run. Therefore the adjustment of these inputs in response to a price shock will be complete only after the capital input is capable to re-equilibrate. Of course this process requires time and studying it requires explicit dynamic treatment (Berndt, Morrison, & Watkins, 1981).

The concept of the adjustment cost was first considered in the neoclassical theory of the firm by Eisner, Strotz, and Post (1963), refined by Lucas (1967), and further by others. There are two types of adjustment costs often suggested by literature: External source, due to monopsonistic elements in the market for new input quantities, in which it incur additional costs over the competitive market price, and depend on the number of additional unit of inputs purchased. The second source of adjustment costs is the internal cost to the firm. For example if a new machine is installed in a particular division of a firm, this may lead to a temporary shut down and possible move of some workers to help in the installation process.

The adjustment cost will be incorporated into the firm's dynamic optimization problem through some functions of the amount of investment in quasi-fixed inputs. Most studies on the dynamic factor demands have adopted the internal adjustment cost formulation. In fact, while external costs may be equally plausible, by their very nature, they do not allow the study of the interactions between the cost of adjusting a specific quasi-fixed input and the level of all the other quasi-fixed input stocks and of variable factors. Clearly, internal adjustment costs permit a richer analysis, relative to external ones, both at the theoretical and the empirical level (Galeotti, 1996).

c. The dynamic factor demand

The three generations of the dynamic factor demand models have been recognized by Berndt et al. (1981) and Berndt and Morrison (1981b). The third generation of the dynamic factor demand has explicitly incorporates dynamic optimization, and thus it provides well-defined results on the short, medium, and long run (Nadiri & Prucha, 1986).

The dynamic aspect of factor demand is important for the studies of the optimal input decisions. Early models were generally characterized by a good instinctive application. However it was lack of foundation in the theory of the firm unqualified the form of the evolution of inputs over time (Galeotti, 1996).

The role of economic theory was limited to the specification of equilibrium input levels. Later developments which relied on adjustment costs have filled the gap. The formulation of the flexible accelerator model by Jorgenson (1963) for one input factor has been further extended and empirically implemented by Nadiri and Rosen (1969) to the case of multiple quasi fixed factors.

The main objective of most empirical studies in the dynamic factor demand models is to estimate the demand and supply elasticities, and in some aspect to estimate the shadow price. As a consequence, the usual investigation has started with selecting a parameterization of the firm’s technology from which, using the results, a simultaneous system of factor demand functions is obtained and subsequently estimated (Galeotti, 1996).

Studies who applied the dynamic factor demand models have mainly adopted flexible functional forms to represent the firm's technology, due to its ability to release many of the priori restrictions imposed on the production structure. For example popular forms such as Cobb-Douglas and constant elasticity of substitution (CES) are said to be inflexible, as they do not allow variable elasticities of output substitution (Chambers, 1983; Diewert, 1974; Diewert & Wales, 1987; Lau, 1986). However flexibility when involved for optimal value functions may be problematic. According to the theory of inter-temporal duality, incorporating flexible functional forms will involve third order derivatives. The flexibility in this case should extend to all second order derivatives. This will limit the number of degree of freedom available from the sample size (Galeotti, 1996). Hence inflexible quadratic form is often proved to be empirically useful functional forms of optimal value functions (Epstein, 1981).

Studies on temporary equilibrium analysis are often concerned with the requirement of a priori knowledge of which input factor of production can be treated in the short-run as variable input. However, a distinction between variable and quasi-fixed inputs has not been initially made in many studies. Different approaches have been proposed to allow for testing if the observed amount of the quasi-fixed inputs is consistent with their long-run cost minimizing levels. For example Kulatilaka (1985), by using aggregated data from US manufacturing, Schankerman and Nadiri (1982) by using US bell system data, and Conrad and Unger (1987) by using data for 28 German industries.

The quadratic functional form is used to assess the magnitude and the functional structure of adjustment costs within temporary equilibrium framework. The quadratic form is suitable to incorporate the restriction of seperability of adjustment costs in applied flexible accelerator models. Galeotti (1990) has provided empirical support to the adjustment cost approach in the dynamic factor demand theory, by finding positive and statistically significant of estimated adjustment costs parameters for two quasi-fixed inputs, suggesting that the cost function is concave in both quasi-fixed inputs.

The cost minimization (or profit maximization) goal of the producer in the industrial sector is subjected to a number of restrictions such as: The production process and its capacity in producing maximum quantity of output given the level of inputs are available and used, a fixed capacity of the firm during a certain time period, knowledge of price and availability of different inputs used in the production process, and the price of their substitutes.

The factor demand functions can be derived from the cost minimization approach, which aims at producing units of outputs up to the level that the rate of technical substitution will be equal to the price of the inputs used (Bhattacharyya & Timilsina, 2009).

A key hypothesis required for determining demand for input factors of production is the profit maximization, which depends on the level of output and a limited combinations of input factors that give a highest production output. This is called a production function in which it explains the maximum level of production given a number of possible combinations of input factors used in the process (Dougherty, 2007).

In sum the dynamic factor demand literature has adopted various modeling approaches, ranging from linear quadratic specifications with an explicit solution for variable and quasi-fixed factors demands, to quadratic and nonlinear quadratic specifications, in which the demand for the quasi-fixed factors is only described in terms of the Euler equations, to specifications in which only the variable factors demand equations are used for estimation. The static equilibrium model is contained as a special case.

In developing methodologies that cover both complex and simple specifications, the dynamic factor demand literature presents a menu of flexible modeling options to empirical researches. The development of methodologies for complex specifications should be interpreted not as a prescription, but also as an option that can be selected when such a choice is indicated empirically.

3.1.2 Inter-factor substitutability and complementarity

In this section, the relevant literature for inter-factor substitutability and complementarity is introduced. The main focus is particularly on the possible substitutability between energy and other input factors of production such as capital and labor. The issues of energy substitutability and complementarity have been widely studied during the last four decades. The empirical results were mixed between energy-capital complementarity and energy-capital substitutability. In the following, the literature and its main findings are presented in chronological order.

An inter-industry production model aimed at energy policy analysis is constructed by Hudson and Jorgenson (1974). They divided the US business sector into nine industries namely agriculture, non-fuel mining and construction, manufacturing excluding petroleum refining, transportation, communications, trade and services, coal mining, crude petroleum and natural gas, petroleum refining, electric utilities and finally gas utilities. By using time series data covering the period 1947–1971, they aggregated the input factors into four main commodity groups: capital, labor, materials and energy. They concluded that energy, capital, and materials are complements in the US industrial sectors.

Berndt and Wood (1975) in a first attempt have empirically tested the substitutability between energy and non-energy input factors. They assumed a Translog functional form in modeling the production structure for the US manufacturing. They consigned an empirical value on the elasticity of substitution, and found that energy demand is price elastic, while energy and capital are having a complimentary relationship.

By using pooled panel data set of manufacturing for nine countries; Belgium, Denmark, France, Italy, Netherlands, Norway, UK, US, and West Germany, Griffin and Gregory (1976) studied the intersubstitutability between energy and capital. They applied the Translog production function representation of technology. In their research, the authors identified the long-run substitutability between energy and capital.

An energy demand model for Canadian manufacturing sector during the period 1949–1970 is estimated by Denny, May, and Pinto (1978). The authors applied a non-homothetic generalizes Leontief cost function. They found that energy and capital are complement. Magnus (1979) applied the generalized Cobb-Douglas cost function using annual aggregate time series data for the Netherlands' economy, covering the periods of 1950–1976. According to his results, energy and labor were substitutes, whereas energy and capital were complements. A pooled, cross sectional and time series data of manufacturing sector for US, Canada, West Germany, Japan, the Netherlands, Norway, and Sweden, covering the period 1963–1974 is used by Ozatalay, Grubaugh, and Long (1979). They estimated a Translog cost function and found that energy and capital are substitutes.

In a ground breaking paper, Pindyck (1979) introduced an econometric model to analyze industrial demand for energy. The model was applied to ten industrial countries Canada, France, Italy, Japan, Netherlands, Norway, Sweden, UK, US, and West Germany, covered the period from 1963 to 1973. His analysis was aiming at determining the level of substitution effects among capital, labor, and energy inputs. Subsequently, a comprehensive literature has been developed based on Pindyck's original model.

By constructing a pooled dataset of ten industries in the US manufacturing sector, Field and Grebenstein (1980) disaggregated the capital stock into physical capital and working capital in their study. The disaggregation was an attempt to reveal the arguments about the role of energy and its relationship's change by capital type. They found a large complementarity relationship between physical capital and energy, while substitutability was observed between working capital and energy.

By incorporating energy and capital investment factors as input substitution and using the Cobb-Douglas production function, Suzuki and Takenaka (1981) found that the Japanese economy will achieve a higher growth rate if it actively substitutes capital for energy. In a similar study, Hazilla and Kopp (1982), by dividing the physical capital into structure and equipment, found complementarity between energy and one component of physical capital, and substitutability between energy and other components of physical capital.

The inter-factor substitutability is investigated by Turnovsky, Folie, and Ulph (1982), using time series data of Australian manufacturing sector during two periods 1946–1947 and 1974–1975 focusing on energy input. They estimated the elasticity of substitution for capital, labor, materials, and energy. They found that energy-capital substitutability. Harper and Field (1983) estimated the elasticity of substitution for capital, labor, materials, and energy for the US manufacturing sectors during the period 1971–1973, using regional cross sectional data, and utilizing a Translog approximation approach. They found that capital and energy are substitute, and the degree of substitution differs by regional location.

A different results were found in the substitutability and complementarity of energy with non-energy inputs by Chichilnisky and Heal (1993). They developed the total cross price elasticity of demand for energy and capital, in which it considers full adjustments in the long-run in multi-sector economy, once the energy price changes in the long-run. Their finding illustrates that the capital and energy's substitutability relationship tends to change into complementarity, once the energy price rises in the long-run.

Hunt (1984) extended the results obtained by Berndt and Wood (1979) through investigating the role of technological progress in production with the presence of factor enhancing technological progress. Hunt's study was conducted through accounting for linear trend as a determinant factor, while Iqbal (1986) applied the Translog cost function to estimate the inter-factor substitutability of labor, capital, energy and fuel types for five manufacturing sectors in Pakistan. She found that labor, capital, and energy are substitutes.

Saicheua (1987) through the use of pooled cross section and time series data of manufacturing sectors in Thailand for the periods of 1974–1977, found the substitutability between input demand factors (capital, labor and energy). In addition, Saicheua found that in all sectors capital and energy were substitutes.

The demand elasticities for energy and non-energy inputs are measured by Siddayao, Khaled, Ranada, and Saicheua (1987) for two industrial sectors in three Asian countries: Bangladesh for the period 1970–1978, the Philippines 1970–1980, and Thailand 1974–1977. They found labor and energy are substitutes, and the elasticity is higher than in the developed countries' industrial sector.

A study conducted by B. C. Kim and Labys (1988) to investigate the long run elasticity between energy demand and price of energy, and the level of inter-factor substitutability. They analyzed the production structure of South Korean industrial sector using pooled time series data covering the period 1960–1980. They found substitutability of energy and capital in the total manufacturing and total industry level, while complementarity in some others sub-industrial sectors.

The factor demands of manufacturing sectors in US and Japan is investigated by Morrison (1988) to characterize the short- and the long-run price elasticities of demand. Her finding was that in both countries the energy and capital are complement, while other inputs are substitutes. Apostolakis (1990) conducted a literature survey on energy and capital relationship. He found that studies used time series data and methodology to capture the short-run effects mainly implied complementarity between capital and energy, whereas studies that used cross sectional data captured the long-run effects implied substitutability between the two factors.

McNown, Pourgerami, and Hirschhausen (1991) studied the substitution elasticities of capital, labor and energy for manufacturing sector in India, Pakistan and Bangladesh. They proved the substitutability of capital and energy using Translog cost function, although the substitutability was differed in elasticity measure in the three countries.

The relationship between economic growth and elasticity of substitution is investigated by Yuhn (1991) through analyzing the inter-factor substitutability between factors of demands (capital, materials, labor, and energy) comparing the South Korean with the US manufacturing sector. The study found the substitutability between capital and energy in both countries under the study. Watanabe (1992) through investigating the substitutability of energy and capital for Japanese manufacturing sector during the period 1970–1987, argued that the energy and capital substitution is resulted from the technological innovation and R&D investment effort that led to faster growth of Japanese industrial technology.

Atkson and Kehoe (1995) derived a model called putty-clay model and applied it to study the equilibrium dynamic of investment capital, wages, and energy. They found that energy and capital are negatively correlated and are thereby substitutes. Christopoulos (2000) used a Translog cost function to model a dynamic structure of production, and to measure the substitutability degree between three types of energy (crude oil, electricity, and diesel), capital and labor. He used the Greek's manufacturing sector time series data covering the period 1970–1990 and found energy and capital are substitutes.

In an attempt to study the substitution relationships in the German economy, Koschel (2000) argued that energy, materials, and capital are substitutes. He applied the Translog function and used a pooled time series and cross sectional data for the period 1978–1990 to estimate price and substitution elasticities between capital, labor, materials, and energy for 50 sectors aggregated into four sectors: energy-supply, energy- intensive manufacturing, non-energy intensive manufacturing, and service sectors. The results showed variations in the degree of substitutability between capital, materials, labor, and energy for the different sectors.

The nested constant elasticity of substitution (CES) of production function, and the elasticity of substitution are estimated by Kemfert and Welsch (2000) using two different datasets for German economy. The datasets included aggregate time series data covering entire German industrial sectors for the period 1970–1988, and a time series data that covered the same period for 7 industries in Germany. The industries involved were chemical industry, stone and earth, iron, non-ferrous metal, vehicles, food, and paper. They found energy and capital were substitutes, based on the aggregated time series data, and the degree of substitutability was differing across the sectors under study based on the second time series dataset.

The role of energy in Pakistan's manufacturing sector is studied by Mahmud (2000), applying the Generalized Leontief restricted cost function and using the manufacturing sector's time series data for the period 1972–1993. He found inter-factor substitutability between energy and capital, and inter-fuel substitutability between electricity and gas.

Frondel and Schmidt (2002) argued that the issue of substitutability and complementarity of energy and capital is not about the econometric methodology as discussed in previous literature such as Apostolakis (1990). Instead, they argued that the estimated Translog cost function for cost share is more appropriate for this issue. Their implication is based on the review of previous empirical works and showed that there is a correlation between cross price elasticity and the cost share of capital and energy due to technological change. In addition, they found evidence of the complementarity occurring only when the cost share of both inputs are small; otherwise, the two inputs are always substitutes.

In addition to his finding about energy-capital substitutability, H. Thompson (2006) emphasized on the degree and direction of this substitutability. He described the substitution of capital and energy inputs through the derivation of cross-price elasticity, using Cobb-Douglas and Translog production and cost functions. In contrast, Kander and Schön (2007) found a high degree of complementarity between energy and capital in a recent study on Swedish industrial and manufacturing sectors for the period 1870–2000. Using a direct measure of technical efficiency, they investigated short- and long-run energy and capital relationships to identify the type of relationship between capital and energy.

Arnberg and Bjorner (2007) applied Translog and linear logit approximation to estimate factor demand models for capital, labor, and energy inputs, using micro panel data of Danish industrial companies for the years 1993, 1995, 1996 and 1997. The authors found labor to be substitutable with energy and capital inputs. Ma et al. (2008) applied a two-stage Translog cost function on a panel data of 31 autonomous regions in China covering the periods 1995–2004. The objective was to measure the elasticities of substitution. They found inter-factor substitutability, i.e. capital and labor are substitutes for energy. In addition to this, they found the inter-fuel complementarity between coal and electricity, and inter-fuel substitutability between electricity and diesel.

Koetse et al. (2008) through their literature survey about elasticity of substitution, applied the Meta regression analysis of previous literature's results and found energy and capital are substitutes, and the degree of the substitutability differs across regions and time periods.

A recent study conducted by Khayyat (2013) to investigate the production risk in the South Korean industrial sectors using a dynamic panel data with Translog specification. His analysis was based on Just and Pope (1978) production risk using balanced panel data model of 25 industrial sectors for the period 1970–2007, focusing mainly on the measurement of the properties of risks related to energy demand and productivity growth. His main findings reveled that ICT capital and labor are substituting energy, ICT capital decreases the variability of energy demand, while non-ICT capital, materials, and labor are increasing the variability of energy demand. Furthermore, he found that technical progress contributes more to increase mean of energy demand than to reduce the level of risk.

In a recent study conducted by J. Kim and Heo (2013), asymmetric substitutability between ICT and energy is discussed and analyzed. They showed that the substitution of energy for capital dominates the substitution of capital for energy despite the fact that energy price increases are greater than capital price increases in the long-run. In another study, the substitutability relation between ICT and energy is shown by Ishida (2014) for Japanese annual data covering the period 1980–2007.

In sum, the review of the comprehensive literature presented above suggests that different specifications for flexible functional forms are used to model production, cost, energy demand or a combination of them depending on the objectives of cost minimization or output maximization. For their empirical analysis the different studies utilized data covering different countries, regions, industrial sectors, and in few case firm levels. The results in general indicate substitution between capital and energy, while complementarity between energy and capital is also frequently observed. The degree of substitutability and complementarity differ significantly by different dimensions of the data and the unit's characteristics.

Based on the literature, Stern (2011) argued that the relationship between energy and output can also be affected by: First, substitution between energy and other inputs, with the literature providing varying conclusions, Second, technological change, and the rebound effect, Third, shifts in the composition of the energy input (energy quality or energy mix), and also the transition of the economy to renewable energy regime; and Fourth, shifts in the composition of output (different industries have different energy intensities.

An ideal model is required to combine theoretical and empirical tools of inter-factor substitution model often called as (KLEM) which refers to capital K, labor L, energy E, and materials M. Further extensions of the inter-fuel substitution, dynamic partial adjustment, demand model for quasi-fixed factors, and econometric model that utilized a flexible functional form are incorporated. Furthermore, explicit treatment of elasticity demand is accounted for in this dissertation in order to identify behavioral characteristics of individual industry, and to derive relevant specific policy variables and recommendations.

3.1.3 The industrial demand for input factors

The estimated industrial demand models for input factors of production can be classified into two main groups: Static models, and dynamic models. Pindyck and Rotemberg (1983) and Morana (2007) argued that a static model is implicitly assumes that all input factors adjust instantaneously to their long run equilibrium values, and hence it cannot depict real economic activity where the adjustment process can only be gradual.

The dynamic factor demand models in the other hand were introduced to address the problems of neglected dynamics, such as parameter instability and serially correlated residuals. According to Morana (2007), the key feature of the factor demand models is the introduction of adjustments costs for quasi-fixed inputs.

The dynamic factor demand models used in this study is the third generation dynamic factor demand model. This study expands the dynamic factor demand model purposed by Nadiri and Prucha (1990) through the use of materials, energy, and labor as variable inputs, and distinguishing the ICT capital from the non-ICT capital. Mun (2002) argued that the traditional neoclassical model of investment assumes the existence of internal adjustment costs from expanding the physical capital stock. Groth (2005) showed that the period of 1990s displayed high growth in ICT investment UK and US, and there exist adjustment costs for ICT capital.

The idea of decomposing the TFP growth allows researchers to identify the sources of productivity growth. The impact of technological change on productivity growth is a major concern in industrial sector. In a recent study, Filippini and Hunt (2011) estimated aggregate energy demand frontier by using Stochastic Frontier Analysis (SFA) for 29 countries over the period 1978–2006. Energy intensity might give a reasonable indication of energy efficiency improvements but this is not always the case. Hence, they suggested an alternative way to estimate the economy-wide level of energy efficiency, in particular through frontier estimation and energy demand modeling.

A parametric frontier approach is proposed by Zhou, Ang, and Zhou (2012) to estimate economy-wide energy efficiency. They used the Shephard energy distance function (Shephard, 1953) to define energy efficiency index, and adopted the stochastic frontier analysis (SFA) to estimate the index by using a sample of 21 OECD countries. It is found that the proposed parametric frontier approach has a higher explanation power in energy efficiency index compared to its nonparametric Data Envelopment Analysis (DEA) counterpart.

The stochastic frontier function has generally been used in the production theory to measure the economic performance of production units, (See for example: Aigner, Lovell, & Schmidt, 1977; Battese & Coelli, 1995; Jondrow, Lovell, Materov, & Schmidt, 1982). The main concept of frontier approach is that the function presents maximum output or minimum level of economic input indicators. Kumbhakar and Lovell (2000) discussed the interpretation of the efficiency in an input requirement function. An input requirement function gives the minimum level of input used by an industry for the production of any given level of output. Most of literature on input requirement function focused on labor use efficiency because labor is an important part of input factors in the production (Battese, Heshmati, & Hjalmarsson, 2000; Kumbhakar, Hjalmarsson, & Heshmati, 2002; Masso & Heshmati, 2004).

Attempts have also been made to analyze the dynamic factor and its adjustment process. Pindyck and Rotemberg (1983) examined how input factors respond over time when changes in the price of energy or output level can be anticipated. The study focused on the importance of adjustment cost and the role of energy as a production factor. Urga and Walters (2003) compared dynamic flexible cost functions to analyze inter-fuel substitution in the US industrial energy demand, while Yi (2000) compared dynamic energy demand models using Swedish manufacturing industries.

The industrial demand for energy has been frequently studied. However, these studies have solely investigated the relationships between energy and non-energy factors. A complementary relation between energy, capital, and labor were investigated based on the US manufacturing time series data. The models have different views of production technology, yet can distinguish the relationships between any two factors in form of complementarity or substitutions. In one example, Jones (1995) analyzed the inter-fuel substitution of the US industrial sectors for the period 1960–1992. He found that the dynamic linear logit model provides global properties that are superior to those of a comparable dynamic Translog models.

Ang and Lee (1994) developed an energy consumption decomposition model using data from Singapore and Taiwan. The authors attempted to identify the effects of structural changes on energy efficiency based on energy coefficient and measures of elasticity of demand. An analysis of the relationship between energy intensity and TFP is conducted recently by Sahu and Narayanan (2011). Their finding indicated that energy intensity is negatively related to TFP, and hence energy use efficiency is required by the industry to operate efficiently.

3.1.4 Efficiency in the use of energy

Energy efficiency is hard to conceptualize, as there is no single or commonly accepted definition. A frequently occurring question concerns the level of detail necessary to carry out a cross-country or a cross-industry comparison without distortions due to structural differences. From the literature, the energy intensity at the national level is calculated as the ratio of energy use to

GDP. This variable is often taken as a proxy for general energy efficiency in production (Ang, 2006). A lower rate of use per unit of output indicates a higher level of efficiency and *vice versa*. At the industry level, it is measured as the ratio of energy use to value of production for a given period or year.

However, there are several limitations regarding this calculation. For example, this aggregate energy consumption to GDP ratio is too simple to explain the economy's energy use patterns. Furthermore, this could lead to difficulties and misunderstandings in interpreting these energy intensity indicators. The energy/GDP ratio includes a number of other structural factors that can significantly affect those indicators. Hence, it is necessary to fix the structural changes effects in measuring energy intensity at the aggregated level in the industrial sectors (Ang, 2004; Boyd, Hanson, & Sterner, 1988).

There are several studies which elaborate with the structural changes challenge. A look at the case of South Korea, Choi, Ang, and Ro (1995) proposed a method to decompose the aggregate energy demand using the Divisia approach by using the data of the manufacturing industries. Three components structural changes, inter-fuel substitution and real energy intensity are distinguished. The results showed that the increase in the aggregated energy intensity since 1988 was mainly due to increase in the real energy intensity, and the contributions from the effect of structural changes and fuel substitution are small. T. Y. Jung and Park (2000) applied the method of real energy intensity to analyze the industrial structural changes effects from the energy intensity. The conventional aggregated energy intensity in the South Korean manufacturing sector had improved by almost three times than the real energy intensity. It is found that the conventional energy intensity could be overestimated, because it contains the effect of structural changes.

As noted above, the energy efficiency is a critical issue for many national energy policies, but surprisingly little attention has been paid to define and measure the efficiency index. However, there is a new effort to calculate the energy efficiency index by using the SFA and DEA approaches. Below are some key literatures that evaluated them:

Boyd et al. (1988) used the SFA to develop an energy performance index (EPI) which is a statistical benchmarking tool of the US EPA Energy Star Program to assess industrial plant energy efficiency. Hjalmarsson, Kumbhakar, and Heshmati (1996) provided a comparison between SFA and DEA, and Heshmati (2003) provided a review of the literature on performance measurement in manufacturing and service industries.

Reinhard, Lovell, and Thijssen (2000) estimated environmental efficiency measures for Dutch dairy farms. They defined environmental efficiency as the ratio of minimum feasible to observed use of environmentally detrimental inputs such as nitrogen surplus, phosphate surplus, and the total energy use. They compared two methods for calculating the efficiency namely SFA and DEA. The result suggested that the environmentally detrimental input is used most inefficiently, both at individual farms and at the aggregate levels. Hu and Wang (2006) analyzed the energy efficiency of 29 administrative regions in China for the period 1995–2002. Unlike several other studies of regional productivity and efficiency in China where energy input is neglected, this study included energy use to find the target energy input using DEA. The index of total factor energy efficiency (TFEE) is defined as the ratio of the target energy input to the actual energy input. The developed area (East) in China has the highest TFEE, the least developed area (West) has the second best rank, while developing area (Central) has the worst rank even though this area shows second highest level of GDP output in China. This U-shaped relationship between the area's TFEE and per capita income confirms that the energy use efficiency has eventually improved the economic growth.

3.1.5 ICT investment and economics growth

Many scholars in recent years have studied the rapid diffusion of ICT and its related hardware, such as computers. Some studies suggested that this fact is a direct consequence of the dramatic decline in the price of computer related equipments, which has led to substitution of ICT equipment to other forms of capital and labor. Accoridngly, they suggested that this substitution has generated substantial returns for those who undertake ICT investment, and also, had a very significant impact on economic growth (Ketteni, Mamuneas, & Pashardes, 2013).

Earlier studies based on aggregated data suggested that ICT have no effect on productivity growth (Berndt & Morrison, 1995; J., 2000; Jorgenson & Stiroh, 1999). However, most of these studies were based on the aggregate production function. They assumed constant returns to scale and competitive markets, and factor shares are often used as proxy for output elasticities. These limitations may affect the estimated relationship between ICT and productivity growth.

A recent movement of research using disaggregated data at industry or sectoral level is witnesed. The argument is that these disaggregated data enable the reseachers to use more adequate methods of estimation, suggesting that firms and industries that produce ICT assets have attracted considerable resources, and benefited from extraordinary technological progress that enabled them to improve the performance of ICT. This is indeed reflected the rapid TFP growth in the ICT industries (Indjikian & Siegel, 2005; Jorgenson, Ho, & Stiroh, 2008; Oliner & Sichel, 2000; Siegel, 1997; Stiroh, 2002).

Most of the studies in the literature mentioned above were based on the US economy. With regard to non-US studies, most of the literature concluded that there is a significant positive relationship between ICT capital and economic growth (Biscourp, Crepon, Heckel, & Riedinger, 2002; Hempell, 2005; Matteucci, O'Mahony, Robinson, & Zwick, 2005). For the case of South Korea, several studies recommended this positive relationship between ICT and economic growth to be further reassessed, especially from the increase of the other industries' productivity as a result of using ICT in their production process (M. Kim & Park, 2009). A study conducted by S. J. Kim (2002) found that the positive effects of ICT on the GDP does not lead to increase in the TFP. An empirical study conducted by H.-G. Kim and Oh (2004) showed that ICT industry was not positively linked to the productivity of the South Korean manufacturing industries. Their analysis was based on the data for the years 1995 and 1998. They concluded that the South Korean economy seems not to be yet of an ICT friendly structure that improves industries' production technology in accordance with the development of ICT.

Another issue highlighted is the existence of ICT spillovers that have a significant impact on the industry's productivity growth (Chun & Nadiri, 2008; Mun & Nadiri, 2002). There exists a nonlinear relationship between ICT and productivity, suggesting that the effect of ICT capital varies among units and time (Ketteni et al., 2013). ICT investment is found to depend on adjustment costs, so that it takes time for productivity gains to be realized (Ahn, 1999; Amato & Amato, 2000; Bessen, 2002; Mun, 2012).

The production structure is studied by S. Park (2014). His study covered 26 industries from six countries: South Korea, US, UK, Germany, and Japan for the period 1971–2007, using the growth and productivity database of EU KLEMS. He estimated a static translog cost function on a panel data assuming three inputs: ICT capital, non-ICT capital, and labor. He found that ICT capital and labor substitutes each other. His finding reveled that although utilizing ICT capital in the industrial production structure aiming at "Creative Economy" will increase the productivity, it will reduce employment opportunity.

The impact of ICT capital on Labor demand and energy use is studied by J. Kim and Heo (2014). Their study covered manufacturing industries and electricity, gas, and water industries for South Korea, US, and UK. They incorporated six inputs of production factors: ICT capital, non-ICT capital, labor, energy, and materials to estimate a static translog cost function coving the period 1980–2007. Based on Morishima elasticities of substitution, they found that ICT capital substitutes labor.

3.1.6 ICT investment and energy use

The relationship between ICT capital investment and energy use is a topic of research that dates back at least as far as the 1950s (White, 1959). Garbade and Silber (1978) studied the substitution effects of telecommunication for transportation in US and some other countries. Their finding revealed that substituting telecommunication for transportation will result in energy conservation. However, the topic did not really start to develop until the early 1980s (see for example:Walker, 1985, 1986).

Coming on the heels of the two oil price shocks in the 1970s, there was a general interest in how to reduce the energy consumption in economies by adopting a greater usage of ICT. The ICT was seen as one possible way to drive the economic growth more efficiently and with less consumed energy. The idea that energy demand in industrialized countries can fall while the economic growth can rise is based on a Schumpeterian view that new information technology will provide large energy saving gains (Walker, 1985). Several studies have investigated how to reduce energy usage in economies by adopting a greater usage of information technology, they have shown that ICT and energy are substitutes (see for example: Campos Marchado & Miller, 1997; X. Chen, 1994; Khayyat, 2013; Watanabe, Kishioka, & Carvajal, 2005).

The effect of a greater information technology use on electricity was often ignored or deemed to be of less of an interest, since many of these studies were conducted before the widespread adoption of the internet and mobile phones (Sadorsky, 2012). In the 1980s, some forward looking authors were pointing out that, while overall energy demand could decrease as economies move towards greater use of information technology, an increased usage of information technology would increase electricity consumption.

The diffusion of ICT and e-business has influenced the level of the energy consumption, air pollution, and greenhouse gas emissions (Fettweis & Zimmermann, 2008; Webb, 2008). However the effect is abstruse. According to European Commission Report (2008), the effect of ICT on energy consumption depends on two factors that are considered countervailing forces: An income effect caused by the economic boost accruing from increased ICT use (increase in energy consumption), and a substitution effect caused by changes in the industrial structure and the capital stock towards higher productivity (decrease in energy consumption). Furthermore, there might also be some substitutions of ICT and energy for labor and/or other input factors of production. Other factors such as industrial structure and the ex-ante patterns of energy use may also affect the relationship between ICT and energy use.

Romm (2002) found that ICT sectors are less energy intensive than manufacturing sectors in the US economy. In the pre-internet period (1992–1996), the US GDP and energy consumption grew at an average yearly rate of 3.2% and 2.4%, respectively. By comparison, in the internet era (1996–2000) the US GDP and energy consumption grew at average yearly rates of 4% and 1%, respectively. There are two different reasons for this decoupling: First, the ICT sectors are less energy intensive than the traditional manufacturing sectors, and second, the internet economy appears to be increasing in efficiency in every sector of the economy.

An argument made by Laitner (2002) reveals that the energy needs in the ICT sector are often over exaggerated. An amount of 3% of the total US energy consumption is required to power ICT needs. His analysis relied heavily on the growing substitution of knowledge for natural resources. He concluded that it is less clear how ICT will affect energy consumption. This is especially the case if a host of new ICT products are developed and widely adopted. Takase and Murota (2004) analyzed the effects of ICT investment on energy consumption and CO2 emissions in Japan and US. They divided the effect of ICT investment into substitution and income effects. They found that the substitution effect is dominant in Japan, while the income effect is dominant in US. In particular, they found that Japan could conserve energy as a result of ICT investment, but the increasing in the ICT investment in US would increase energy use.

By applying a static factor demand model to analyze the relationship between ICT and energy in the French service sector, Collard et al. (2005) found that, after controlling for factors such as technical progress, prices, and heated areas, electricity intensity of production increases with computers and software, while it decreases with the diffusion of communication device. In other words, the communications technology impact is greater than the information technology impact.

Bernstein and Madlener (2010) applied a static factor demand model to empirically analyze the effects of ICT capital on the electricity intensity in five major European manufacturing industries: Chemical, food, metal, pulp and paper, and textile. The analysis was based on an unbalanced panel including data for eight EU member countries: Denmark, Finland, Germany, Italy, Portugal, Slovenia, Sweden, and UK for the period 1991-2005. They found electricity saving effect on production which involve ICT, and the net effect of ICT diffusion on electricity intensity of production enhanced the electricity efficiency in production.

The European Commission e-Business Watch (2008) conducted a comprehensive study of the effects of ICT on electricity usage in three industries: Chemical, metal, and transport for a number of European countries: Austria, Denmark, Finland, France, Germany, Italy, and Spain.

Their finding was that at the aggregate level, ICT may not necessarily reduce electricity intensity of absolute levels of electricity consumption. However, at the sector level, the diffusion of ICT has a positive impact on reducing electricity intensity, while the diffusion of computer and software technologies tends to increase electricity intensity.

As illustrated in the previous section, with the exception of Y. Cho, Lee, and Kim (2007) in the context of South Korea industries, not many researches are conducted in this respect. Moreover, in order to confront possible future energy crises, the consumption of energy should be restructured and reduced. The impact of ICT investment and price of energy on electricity consumption in the industrial sector of South Korea has been studied by Y. Cho et al. (2007). They explained the electricity consumption pattern based on the concept of electricity intensity using logistic growth model. The results showed that ICT is reducing the demand for electricity in some manufacturing sectors.

According to a recent study conducted by J. Kim and Heo (2014), the ICT capital substitutes electricity and fuel in the US and the UK manufacturing sectors. Although the ICT capital, electricity, and fuel have inter-substitution effects in the South Korean manufacturing sectors, the ICT capital is unlikely to decrease the demands for electricity and fuel when considering their relative price changes.

3.1.7 The total factor productivity

Although the recent development of the growth models have emphasized mainly on the role of innovation and knowledge based capital formation as an engine driver to sustain long run economic growth (Freeman & Soete, 1997; Grossman & Helpman, 1991; Lucas Jr, 1988). Studies related to the economic growth of the East Asian countries found that most of the economic growth is driven by input factors of production, rather than technological progress (Collins & Bosworth, 1996; Krugman, 1994; Stiglitz, 1996). Accordingly the literature on economic growth have concentrated more on studying and identifying the determinants of TFP as the drive engine of long-run economic growth (T. Kim & Park, 2006).

Measuring the TFP growth is not a straightforward exercise, the measurement is undermined by a number of conceptual and empirical issues, none of which has been satisfactorily resolved in the literature. The literature has followed mainly two approaches for the productivity measurement: First, those studies that based on the estimation of a technological frontier, showing what is feasible for best practice firms, and second, those based on averaging process, reflecting what has been achieved by representative firms in the industry. Within the latter, non-frontier approach, the traditional measures of TFP growth include the index number approach (which also encompasses the growth accounting methodology), and the econometric production (or cost) function approach are applied.

While overall productivity growth results that are obtained through implementing the mentioned methods are meaningful on their own, it is important to understand the different sources through which such growth are arisen. Hence, a decomposition of the TFP growth is necessary to identify these sources (Vencappa, Fenn, Diacon, & Campus, 2008).

The literature on measuring the sources of productivity change can essentially be summarized under two approaches: First, top-down approach where a measure of TFP growth is obtained and an interpretation of the measure is required. For example, do the estimated parameters represent pure technical change, or do they also capture efficiency change? Under this approach, it is possible that some of the TFP growth may not be sufficiently accounted for, and interpretation of the results may become difficult. Second the bottom-up approach, in which all possible sources of the productivity growth are first identified, and then estimated in the best possible way. These estimates are then appropriately combined to construct a measure for the TFP growth (Vencappa et al., 2008).

The bottom-up approach is applied by Balk (2001) to discuss four sources of the productivity growth: Technical change, which arises through a shift in the production technology, efficiency change, which arises as a result of the firm's ability to use its inputs more efficiently to produce its output given the existing technology, the scale efficiency change, whereby a firm is able to produce at levels of operations closer to the technologically optimum scale of production, and lastly the output mix effect, which captures the effect of the composition of the output mix on scale efficiency. Several methods are applied since 1990s to measure the productivity growth either at the aggregate level, or at the industrial level.

Most early studies before the mid–1990s have estimated the TFP growth rate using Solow's residual method or the growth accounting method. There is no consensus about adequate rates of the TFP growth in the process of economic growth, as they fluctuate widely among countries and periods (F. S. T. Hsiao & Park, 2005). The residual method is often considered to be rather misleading, and to provide little insights into the determination of the productivity growth (Nelson & Pack, 1999).

In addition to Solow residual, several empirical works on economic growth used the Tornqvist productivity index to measure the TFP. However the Malmquist index has gained considerable popularity in the measurement of TFP since Färe, Grosskopf, Norris, and Zhang (1994) applied DEA approach, to calculate the distance functions that make up the Malmquist index. They showed that Malmquist productivity index is more general than the Tornqvist index, as it allows for inefficient performance, and does not require an underlying functional form to specify the technology.

The reason for the index's increasing in popularity is that the Malmquist productivity-change index depends only on the quantity of information; it does not require price information or behavioral assumption in its construction. Most importantly, it allows for the further decomposition of the TFP growth into changes in efficiency and changes in technology (P. C. Chen, Yu, Chang, & Hsu, 2008). Such decomposition will facilitate the way measures the sources of changes in the productivity, and it is important for facilitating a multilateral comparison that may help explain and characterize the differences and similarities in the growth patterns for different regions. Such decomposition of TFP may be useful for policy makers as they may consider it important to know whether technological progress accelerated over time, or whether the given technology has been used in such a way as to realize its full potential (Chang & Luh, 1999). Because technical advances and efficiency change constitute different sources of the TFP growth, different policies may be required to address them.

However, Malmquist productivity index is incomplete since it accounts for the sources of TFP growth that arising only from technical change and efficiency change. A study conducted by J.-D. Lee, Kim, and Heo (1998) to estimate the Malmquist productivity index and its two components for the South Korean manufacturing sectors during the period 1967–1993, found that productivity was achieved through technical progress, and efficiency change negatively contributed to the productivity growth. The same results were found for the Taiwanese manufacturing regarding the negative effects of technical efficiency on the TFP growth (Färe, Grosskopf, & Lee, 1995, 2001). While other studies based on cross-countries comparison found that efficiency improvement has higher effect than technical progress in the developing countries, including South Korea (Chang & Luh, 1999; Cook & Uchida, 2002; T. Kim & Park, 2006; Kruger, Canter, & Hanusch, 2000; Taskin & Zaim, 1997).

3.2 Contribution to the Literature

In the empirical work of this dissertation study, the factor demand equations are estimated on a panel data of 30 industries for the period 1980–2009. The factor demand equations are conventionally estimated on time series data for a given industry or sector, which is reasonable under the hypothesis that cost function parameters are invariant over time but not necessarily across industries.

It is much less reasonable to maintain the convenient assumption that (relative) input price such as wage rates, are exogenous at the aggregate level than it is at the industry level.

By including the industry effects (industry dummies), this study could control for the effects of any permanent differences across industries in unmeasured determinants of the factor demand. A chi-square test has been performed showing that the dummy variables are jointly significant and should be included in the system estimated.

The time trend *T* controls for the effects of changes over time in unmeasured determinants which are common to all industries. *T* is controlled for by the industry and year effects. However, industries may experience different rates of technical change, so that not all of the variations in *T* will be captured by the fixed effects. Of course, if technical progress is, in reality, neutral with respect to the structure of input demand, then there will be no specification error by omitting *T* from the demand equations (Khayyat, 2013).

Studies on South Korean productivity have mainly applied non-parametric approach to estimate the TFP at country aggregated level (M. Kim & Park, 2009; Pyo, Rhee, & Ha, 2007), and at micoeconomic industrial level (Ahn, Fukao, & Kwon, 2004; Aw, Chung, & Roberts, 2003; Hahn, 2005; I. Oh et al., 2009). However relatively little attention has been paid to parametric approach based estimate for TFP. In a recent study that applied a parametric approach conducted by D. Oh, Heshmati, and Lööf (2014) to investigate the patterns in the South Korean manufacturing industries' TFP growth for the 'roller-coaster period' 1987–2007, revealed that large firms and high technology industries show a higher rate of TFP growth.

The main weakness of the non-parametric approach is that it does not account for statistical noise to be separated from the effects of inefficiency, and hence, it is therefore vulnerable to outliers and generating biased results (O. S. Kwon & Lee, 2004).

This study adopts a parmteric aprocah based on cost function specification to analyze productivity and decompose the TFP using the third generation dynamic factor demand model. Hence this study does not assume a long-run equilibrium and constant returns to scale hypotheses that are not likely to be valid in high-tech and in capital intensive industries (I. Oh, Lee, & Heshmati, 2008). In addition to the abovementioned, the main contribution of this dissertaion study to the literature can be summarized as follows:

1. The data used to estimate the energy demand in previous literature were mainly of two types: Cross sectional data within a country, in which it is considered inadequate due to the effects of location that exaggerate the elasticities such as price elasticity. The other data type used is the international cross sections, which also insufficient due to structural differences that direct the elasticities away from zero. Hence, the pooled time series or pool cross sectional data is more desirable, as it addresses the shortcoming mentioned above by powerful econometric techniques such as flexible production function (Hartman, 1979). The model also allows capturing both dynamics and heterogeneity in production and factor demand.
2. The main contribution of this dissertation study is that the estimated models can fully exploit the panel nature of a dataset. Previous dynamic factor models have considered multiple attributes over several time periods but only for a single individual firm or economy (Stock & Watson, 1989). Even when multiple individuals are considered, only a single unobserved index, common for all

individuals, is estimated for every time period (Forni, Hallin, Lippi, & Reichlin, 2000).

This study develops a generalized dynamic factor model which varies both across individuals and across time to estimate the optimal input path index, TFP index, and capacity utilization index both at industry level and across time.

3. In order to shed lights on the ICT and energy demand relationship, this dissertation study is conducted by incorporating the ICT investment as an input factor of production. Various elasticities such as own price, cross price, level of industrial activity, and effects of other control variables are estimated.

   This dissertation contributes to the literature by investigating the sources of growth and ICT capital use, its relation with the energy consumption, and the decomposition of TFP growth. The estimated model allows to capture the effect of input prices on the demands for all inputs under consideration (therefore capturing the own and cross price effects), and allow the efficiency gains in production to arise when new inputs generate an improvement in technical efficiency that is not fully offset by the adjustment cost.

4. Previous studies that investigated the effects of ICT on energy have conducted based on either individual industry or firm level, or based on national level. These studies are not able to provide adequate policy suggestions.

   An empirical contribution of this study is that no previous studies applied the dynamic factor demand model to investigate the relationship between the ICT investment and energy consumption in such detailed industrial level. This allows to provide extensive and accurate policy suggestions for individual industries. In the future, studying the other input factors of production may attract the researchers and policy makers. This study then, can be considered as a platform for analyzing the relationship between two or more of those input factors of production.

In this dissertation study, a dynamic factor demand is modeled which embodies the rational expectations aspect and a dynamic optimization in the presence of adjustment costs. Such a model specification provides an a appropriate framework to assess the effects of energy price on sectoral production costs and input demand, because it accounts for the fact that energy is closely tied to energy-using technology.

Investments in new capital, for example in energy-saving technology, do not simply lead to efficiency gains; they also involve adjustment costs in the short-run. Based on the empirical results obtained from the empirical analysis, this dissertaion study constructs the price elasticities (total and by industry) to investigate whether energy inputs behave complements or substitutes to both types of capital (ICT and non-ICT), and other input factors of production.

In order to examine how changes in prices and inputs affect the investment behaviour, employment, and energy use, it is essential to employ a dynamic model. The assumption of instantaneous adjustment of all inputs to price changes may not be very useful. For instance, under energy price shocks when occur, the utilization rates of the various surviving vintages of capital (as well as other inputs) are adapted, which also affects the flow of services per unit of capital (Ketteni et al., 2013).

For ilustraion, if energy and capital are at least short-run complements, then increase in the energy price will cause the marginal product of capital, and thus capital utilization to decline. It would cause errors in standard measures of technical change. This in turn would cause diminished technical change through reduced incentives to invest in new equipment that embodies new technology. Thus, the impact of energy price changes is difficult to identify without an appropriate modelling framework of a firm's production decisions and performance.

3.3 Significance of the Study

This dissertation study 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 the 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, environmental policy makers; and in its message to industrial sector's stakeholders the policy makers and the regulators; the new entrants or the investors who might be contemplating to enter the industrial sector, and finally 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 in two points: 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 sectors especially in the high energy consumed countries such as China, US, North America, 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. According to 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, Almonacid, & Hontoria, 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 methods such as dynamic model specification is highly desirable, as it allows for flexibility in adjustment of the input factors in the long-run (B. C. Kim & Labys, 1988). Although the dynamic model formulation may lead to increase complexity in modeling, estimation, and interpretation of the results, it may has the advantage of deriving the elasticities as well as accounting for responsive heterogeneity over time and by industry characteristics.

3.4 Summary

The factor demand and the cost function within the framework of the theory of the firm's optimal input decisions, in a non-static context is discussed in detail in this chapter.

The most relevant and related studies of production theory often divided into the cost function (dual approach) studies and technology flow (primal approach) studies. The dual approach studies rely on four concepts: the neoclassical theory of investment, the duality theory, the advances in flexible functional forms, and the various developments in the inter-temporal modeling of adjustment costs. This dissertation study adapted the dual approach in estimating the production structure of the South Korean industrial sectors.

The dynamic aspect of factor demand is important for the studies of the optimal input decisions based on adjustment cost approach. The dynamic factor demand literature presents a menu of flexible modeling options to the empirical researcher. Although the dynamic model formulation may lead to increase complexity in modeling, estimation, and interpretation of the results, it may has the advantage of deriving the elasticities as well as accounting for responsive heterogeneity over time and by industry characteristics.

From the study of inter-factor substitutability and complementarity between energy and other factors of production, it was found that there are two directional approaches: One claims the substitutability, and the other claims complementarity, and both are providing strong theoretical and empirical evidences. For their empirical analyses, these studies have utilized data of different countries, regions, industrial sectors and in a few cases, based on firm levels. The results in general indicate substitution between capital and labor while complementarity between energy and capital is also frequently observed. The degree of substitutability and complementarity differ significantly by different dimensions of the data and the unit's characteristics.

Firms and industries that produce ICT assets have attracted considerable resources and benefited from extraordinary technological progress that enabled them to improve the performance of ICT goods. This is reflected in the rapid TFP growth in the ICT industries.

Measuring the TFP growth is undermined by a number of conceptual and empirical issues none of which has been satisfactorily resolved in the literature. The literature has followed mainly two approaches to productivity measurement: Studies based on the estimation of a technological frontier showing what is feasible for best practice firms, and studies based on averaging process reflecting what has been achieved by representative firms in the industry. Within the latter, non-frontier approaches, the traditional measures of TFP growth include the index number approach and the econometric production (or cost) function approach. The stochastic frontier function has generally been used in the production theory to measure economic performance of production units. The industrial demand for energy has been frequently studied but these studies solely investigated the relationships between energy and non-energy factors.

The factor demand equations are conventionally estimated on time series data for a given industry or sector. However, It is much less reasonable to maintain the convenient assumption that input price such as wage rates are exogenous at the aggregate level than it is at the industry level. By including the industry effects (industry dummies), this study could control for the effects of any permanent differences or heterogeniery across industries in unmeasured determinants of the factor demand.

Most of the studies relarted to the South Korean productivity measurement have mainly applied non-parametric approach to estimate the TFP at the country aggregated level, or at the micoeconomic industrial level. However relatively little attention has been paid to parametric approach based estimate for TFP. The main weakness of the non-parametric approach is that it does not account for statistical noise to be separated from the effects of inefficiency, and is therefore vulnerable to outliers, generating biased results.

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

Chapter 4: Description of Data

4.1 Data Source

The data used in this study is obtained from different sources, mainly from the harmonized Asia KLEMS growth and productivity accounts database (June 2012 release)[3] for South Korea, and the EU KLEMS growth and productivity accounts database for Japan. These databases include variables that measure output and input growth, as well as derived variables, such as multi-factor productivity at the industry level. The input measures include various categories of capital, labor, energy, materials, and ICT capital inputs.

The main objective of the KLEMS growth and productivity database is to support empirical studies, as well as theoretical research in areas related to economic growth, productivity, skill formations, innovation, and technological progress (O'Mahony & Timmer, 2009). The data in Asia KLEMS growth and productivity database contains varieties of basic input data series derived separately from the growth accounting assumptions methodology. Different categories and classes of capital, labor, materials, and energy are provided in cooperation between Asia KLEMS consortium partners and national statistic offices in the partner countries (Pyo, Rhee, & Chun, 2012).

The dataset provides a clear conceptual framework in which the interaction between variables can be analyzed in an internally consistent way. The greatest advantage of this data set is that it provides data series for almost entire organized industry sectors. The capital compensation is derived as the

[3] The database is publicly available at: “http://asiaklems.net/”.

difference between the value added and the labor compensation. The labor compensation variable is derived using the proportion of total hours worked by total involved persons to total hours worked by employees to compensation. Other inputs such as materials and energy are computed from the share of each of these inputs from the national account. The energy input is an aggregate of energy mining, oil refining, electricity, and gas products (O'Mahony & Timmer, 2009).

The real non-ICT capital stock (converted to 2005 price) is taken from the Korea Industrial Productivity Database (KIP) 2012[4]. The macro economic variables have been taken from the Bank of Korea (BOK) Economic Statistics System (ECOS)[5]. In addition to the variables mentioned above, this study utilizes measures for an export/import oriented industry, the level of R&D intensity, and labor skills categories of high, medium, and low, all developed for 31 main industrial sectors in South Korea. The focus of this study uses data that covers the period from 1980 to 2009 and consists of 900 observations.

The rental rate of capital stock is defined as $p^K = p_K(\delta + r)(1 - \tau)$ where pk is the chained fisher price index of capital stock, δ is the physical capital deflator, r is the real discount rate, and τ is the corporate tax income equal to 0.30. The macroeconomic variables for the Japanese analysis are taken from the Bank of Japan database[6]. The Japanese part of the EU KLEMS database includes 72 industries, but only those matching the corresponding Korean industries are used for the comparative analysis.

[4] The database is publicly available at: "http://www.kpc.or.kr/eng/state/2012_kip.asp?c_menu=5&s_menu=5_4".
[5] The dataset is publicly available at: "http://ecos.bok.or.kr/EIndex_en.jsp".
[6] The dataset is publicly available at: "http://www.stat-search.boj.or.jp/index_en.html/".

A discussion of the input price indices follows. The price indices for ICT capital and non-ICT capital (Ip_ICT and Ip_NonICT) are given by the EU KLEMS growth and productivity database, under the section “Gross fixed capital formation price index (1995=1.00) for ICT and non-ICT assets”. The indices are then converted to 2005 prices to match with the figures obtained from the Asia KLEMS growth and productivity database, in which all the figure are expressed in 2005 prices. The labor price (the variable LAB_QPH) is defined as the labor services per hour worked, using 2005 as the reference year [7]. The figures are divided by their corresponding figures of 2005 and multiplied by 100 to obtain the labor price index Ip_Lab (2005=1.00). The price index for intermediate inputs (the variable II_P which is given by the EU KLEMS and the Asia KLEMS growth and productivity database) is used for energy and materials.

As described by Pyo et al. (2012), there has been some confusion in the literature concerning the price and its use for intermediate goods. Most studies agree on using the consumer purchase price which includes payable taxes on goods and the margins on trade and transportation (when trade and transportation are included as separate products), but excludes the subsidies on goods. However, as clearly explained by O'Mahony and Timmer (2009), the EU KLEMS was not able to collect the necessary data to cover the mentioned issues above, and instead uses the purchase price to value intermediate inputs in all cases except for the US. The constructed price indices for the input factors of production, as well as the additional constructed variables are reported in in Table 4.1. The constructed price

[7] This variable is measured by accounting for heterogeneity in the labor force and the productivity of various types of labor (based on skill, gender, education, etc.).

indices for the input factors of production and constructed variables based on other variables are reported in Table 4.2.

Table 4. 1

Definition of Variables

Variable	Description	Source
Sector	30 industries are selected	Asia KLEMS Growth and Productivity Database for Korea and EU KLEMS Growth and Productivity Database for Japan
Year	1980-2009 for Korea, 1973-2006 for Japan	Same as above
GO	Gross output at current purchasers' prices (in millions of Korean Won)	Same as above
GO_P	Price Index of Gross Output (Index, 2005=100)	Same as above
VA	Gross value added at current basic prices (in millions of Korean Won)	Same as above
CAPIT	ICT capital Stock (share in total capital compensation)	Same as above
H_EMPE	Total Hours worked by Employees (in Millions)	Same as above
LAP_QPH	The labor services per hour	Same as above

	worked, 2005 reference	
PMM	Intermediate materials inputs at current purchasers' prices (in millions of Korean Won)	Same as above
IIE	Intermediate energy inputs at current purchasers' prices (in millions of Korean Won)	Same as above
Ip_ICT	Price Index of ICT Capital Stock, 2005 = 100	Same as above
Ip_NonICT	Price Index of non-ICT Capital Stock, 2005 = 100	Same as above
II_P	Intermediate inputs, price indices, 2005 = 100	
TXSP	Other taxes minus subsidies on production (in millions of Korean Won)	Same as above
Kstock	The capital stock (in millions of Korean Won)	The Capital Stock is taken from the Korea Industrial Productivity Database for Korea, and from EU KLEMS for Japan.
CITR	Corporate Income Tax Rate	OECD Statistics Database
LTGOVBR	Long-Term Government Bond Interest Rate	Bank of Korea, Bank of Japan
INFLATR	CPI Inflation Rate	Bank of Korea, Bank of Japan
RIR	Real Interest Rate=LTGOVBR - INFLATR	

Table 4. 2

Constructed Variables

Variable	Formula	Source
ICTDR	ICT Capital Depreciation Rate =0.248%	The service life is 7 years for hardware, 5 years for software, 11 years for telecommunication equipment, and 30 years for other assets (aggregated as non-ICT assets. These service lives can be approximated by using a geometric depreciation rate of 0.315% for hardware and software, 11% for telecommunication equipment, and 7.5% for non-ICT assets (O'Mahony & Timmer, 2009);
CDR	Non-ICT Capital Depreciation Rate: The Average Depreciation Rate of Machinery, Transport Equipment, and Non-Residential Structure	Asia KLEMS Growth and Productivity Database for Korea and EU KLEMS Growth and Productivity Database for Japan
Ip_Lab	Price Index of Labor	Calculated based on LAP_QPH
I	ICT Capital Stock (in 2005	The share is taken from the

	Prices), i.e . (CAPIT * Kstock)	Asia KLEMS database, multiplied by the Capital Stock
K	Non-ICT Capital Stock (in 2005 Prices), i.e. [Kstock-(CAPIT*Kstock)]	The physical share of non-ICT Capital is calculated after subtracting the real share of ICT Capital
PFPICT	(Ip_ICT)*(RIR+ICTDR)*(1-CITR)	ICT Capital Rental Price Index
PFPK	(Ip_NonICT)*(RIR+CDR)*(1-CITR)	Non-ICT Capital Rental Price Index
QICT	(I/PFPICT)*100	Quantity of ICT Capital Stock
QK	(K/PFPK)*100	Quantity of Non-ICT Capital Stock
QL	(H_EMPE/LAP_P)*100	Quantity of Labor
QE	(IIE/II_P)*100	Quantity of Energy
QM	(IIM/II_P)*100	Quantity of Materials
QGO	GP/GO_P	Quantity of Gross Output
DIFQK	QK(t)-QK(t-1)	Internal non-ICT Capital Adjustment Cost (in terms of foregone output due to changes in quasi-fixed factors)
DIFQICT	QICT(t)-QICT(t-1)	Internal ICT Capital Adjustment Cost (in terms of foregone output due to changes in quasi-fixed factors)

4.2 Population and Sampling Strategy

The dataset for this dissertation study is comprised of 900 observations from 30 main industries in South Korea observed for the period 1980–2009. The dataset for Japan is comprised of 990 observations from 30 main industries observed for the period 1973–2006.

The data include a number of variables pertaining to the industry's level of input-output production data, as well as the industry's level of demand for energy and industry and time period characteristics. A summary statistics for the variables and its raw data is presented in Table 4.3 and Table 4.4 for South Korea and Japan, respectively.

The variables used in this dissertation include in addition to the key input factors mentioned in the previous section, values for price of energy, volumes, growth accounting, and related macroeconomic variables. The variables of monetarily measured for example intermediate inputs, gross output, and gross value added are all given in fixed 2005 prices.

Table 4. 3

Summary Statistics of the Raw Data, in 2005 prices-South Korea, No of Obs. =900

Variable	**Mean**	**Std. Dev**	**Min**	**Max**	**Coeff. of Variation**	**t Value**
sector	15.5	8.6603	1	30	55.8726	53.69
year	1994.5	8.6603	1980	2009	0.4342	6909.2
Gross Output	31205044.1	38595815.4	277866	294907540	123.6845	24.26
Energy	2304646.6	7096103.76	12211	107224600	307.9042	9.74
Labor	6464268.46	8402458.18	42838	48853944	129.9831	23.08
Labor Hours	4839.0398	5120.2863	44.85	32876.26	105.812	28.35
High Skill Labor	0.1352	0.0563	0.04	0.55	41.6678	72
Mid- Skill Labor	0.6104	0.0658	0.38	0.74	10.7806	278.28
Low Skill Labor	0.2537	0.0986	0.01	0.56	38.867	77.19
Materials	10738245.6	20785299.2	21156	168760400	193.5633	15.5
Share of ICT	0.1384	0.0844	0.0003	0.3632	60.9927	49.19
Interest Rate	11.5697	5.5373	4.45	28.76	47.8606	62.68

Tax	149689.183	340698.809	1107	3878578	227.6042	13.18
Inflation Rate	4.4867	2.2975	0.3	8.7	51.2065	58.59
discount Rate	4.564	1.7781	1.27	7.83	38.9596	77
GDP Deflator	69.12	26.2466	26.8	108.5	37.9726	79
Capital Stock	33609982	61665236.7	460051.4223	506521566	183.473	16.35
ICT Stock	3719493.37	4420097.07	9690.3419	23701822.8	118.836	25.24
ΔCapital	2440805.66	4455005.59	-4558392.97	42602862.4	182.5219	16.44
ΔICT	278423.428	389798.06	-933905.291	3088019.22	140.0019	21.43

Table 4. 4.

Summary Statistics of the Raw Data, in 2005 prices-Japan, No of Obs. 1020

Variable	Mean	Std. Dev	Min	Max	Coeff. of Variation	t Value
Sector	15.5	8.6597	1	30	55.869	57.16
Year	1989.5	9.8155	1973	2006	0.4934	6473.37
Gross Output	24003615	17894379	1189386	93636658	74.5487	42.84
Energy	476775.2	590175.5	3176.147	4966420	123.7849	25.8
Labor	7439580	7062330	19286.79	33978632	94.9291	33.64
Labor Hours	2549.668	978.3643	550.0959	5129.71	38.3722	83.23
High Skill Labor	22.6371	13.4025	4.1756	77.743	59.206	53.94
Mid- Skill Labor	55.0189	11.4415	21.6831	80.6896	20.7955	153.58
Low Skill Labor	22.344	16.3463	0.5739	70.8348	73.1574	43.66
Materials	6596859	6836323	64011.09	34843152	103.63	30.82
Share of ICT	0.0914	0.1177	0.0007	0.7067	128.815	24.79
Interest Rate	2.8294	1.6535	0.84	6.96	58.441	54.65

Inflation Rate	3.4106	2.5547	0.28	9.25	74.9037	42.64
Discount Rate	3.2838	2.7211	0.1	9	82.8648	38.54
Capital Stock	38512432	78893331	1394313	6.84E+08	204.8516	15.59
ICT Stock	1201295	3010083	1596.546	33509975	250.5698	12.75

The ASIA KLEMS growth and productivity account database provides also capital and labor compensations and their volume and additional variables such as skilled labor compensation and ICT capital compensation and their volumes. Prior to estimation, the input levels are normalized to their sample means. This procedure will simplify the analysis of estimated elasticities particularly for the variance function (Wooldridge, 2006). It also ensures that data is distributed symmetrically, it ensures a better equally dispersion across various levels, it also benefits when it constructs linear relationships between the variables.

4.3 Classification of the Industrial Sectors

The industrial sectors are classifies into 31 industries using the international industry classification system (U.N., 2008). The EU KLEMS (and ASIA KELMS) growth and productivity account database provides subordinate structure of the industries more precisely (See Table 4.5). Even though the industrial sectors for South Korea and Japan are divided in more detailed form in the growth and productivity account database, it does not provide energy data. In this case, the upper classification containing sub-industries is used.

Table 4. 5

Classification of the Industrial Sectors

ID	Description	Technology Level	Market Ordination	R&D Intensity
1	Agriculture, Hunting, Forestry and Fishing	L	L	M
2	Mining and Quarrying	L	L	L
3	Food , Beverages and Tobacco	L	M	M
4	Textiles, Leather and Footwear	L	I	M
5	Wood and Cork	L	L	L
6	Pulp, Paper, Printing and Publishing	L	M	H
7	Coke, Refined Petroleum and Nuclear Fuel	H	L	H
8	Chemicals and Chemical Products	H	I	M
9	Rubber and Plastics	H	I	M
10	Other Non-Metallic Mineral	M	M	M
11	Basic Metals and Fabricated Metal	M	M	L

12	Machinery, NEC	H	I	H
13	Electrical and Optical Equipment	H	I	H
14	Transport Equipment	H	I	M
15	Manufacturing NEC; Recycling	H	I	M
16	Electricity, Gas and Water Supply	M	L	H
17	Construction	H	I	H
18	Sale, Maintenance and Repair of Motor Vehicles and Motorcycles; Retail Sale of Fuel	L	L	L
19	Wholesale Trade and Commission Trade, Except of Motor Vehicles and Motorcycles	L	L	L
20	Retail Trade, Except of Motor Vehicles and Motorcycles; Repair of Household Goods	L	L	L
21	Hotels and Restaurants	L	L	L
22	Transport and Storage	M	L	L
23	Post and Telecommunications	H	I	H
24	Financial Intermediation	M	L	H

25	Real Estate Activities	L	L	L
26	Renting of M&Eq and Other Business Activities	L	L	L
27	Public Admin and Defense; Compulsory Social Security	L	L	L
28	Education	L	L	H
29	Health and Social Work	H	L	L
30	Other Community, Social And Personal Services	L	L	L
31	Private Households with Employed Persons	L	L	L

The figures reported in Table 4.5 reflect the fact that each industry has unique characteristics concerning concentration, technology level, scale of R&D investment, and the degree of export orientation. For this study the total industry is divided into three groups in terms of technology concentration. The technology level is classified as high (*H*), medium (*M*), and low (*L*) through the industry sector's international classification. Note that the number of industries under the study in terms of technology level is 16, 5, and 10 for low, medium, and high technology, respectively.

The degree of export orientation is categorized according to the industry sector classification as international (*I*) for international market or export oriented, mixed (*M*) as mix between international and domestic, and local (*L*) for domestic only oriented market. There are 9 industries classified as export oriented market, 18 as domestic, and only 4 are classified as mix market.

The scale of research and development activities R&D is also derived and classified as (*H*) for high level spending, (*M*) for medium spending, and (*L*) for low-level spending. From the total of 31 industries, 9 industries are classified as High R&D intensive, 8 industries as Medium R&D intensive, and 14 industries as low in R&D intensive.

4.4 Energy use Intensity in the Industrial Sectors

In general, due to the difference in the production process, some industries consume higher rate of energy per unit of output than other industries. This difference is often labeled as heterogeneity in industries' energy use. Various groups of industrial sectors such as manufacturing, chemical, mining, agriculture, and fisheries are consuming energy for different purposes and activities such as space conditioning, lightening, processing, and assembly (IEA, 2011).

The nature of activities explains much of the variations in energy use per unit of output. Table 4.6 shows relative energy intensity in the South Korean industrial sectors. The figures are calculated as follows: First the energy intensity indicator is calculated by dividing the amount of energy use in year *t* for industry *i* by the corresponding value added figures. Second, the figures are averaged over a decade (10 years) per industry, and third the figures obtained for decades are used to calculate the trends. The trends are obtained by differencing two consequence decades divided by the later decade. For example the trend 1980–1990 is obtained through differencing the figures of 1980s from 1990s, and then dividing by 1990s figures.

Table 4. 6

Energy Intensity (per value added) in the South Korean Industrial Sectors, 1980-2009

ID	Sector	Decades			Trends	
		1980s	**1990s**	**2000s**	**1980–1990**	**1990–2000**
1	Agriculture, Hunting, Forestry and Fishing	0.040	0.037	0.059	-0.077	0.572
2	Mining and Quarrying	0.186	0.109	0.146	-0.412	0.340
3	Food , Beverages and Tobacco	0.268	0.124	0.080	-0.535	-0.353
4	Textiles, Leather and Footwear	0.316	0.205	0.137	-0.351	-0.330
5	Wood and Cork	0.350	0.198	0.168	-0.434	-0.150
6	Pulp, Paper, Printing and Publishing	0.168	0.120	0.156	-0.289	0.302
7	Coke, Refined Petroleum and Nuclear Fuel	0.350	2.345	5.791	5.710	1.469
8	Chemicals and Chemical Products	1.031	0.615	0.696	-0.403	0.132

9	Rubber and Plastics	0.994	0.411	0.125	-0.586	-0.697
10	Other Non-Metallic Mineral	0.512	0.363	0.443	-0.291	0.219
11	Basic Metals and Fabricated Metal	0.381	0.224	0.264	-0.413	0.179
12	Machinery, NEC	0.124	0.097	0.072	-0.219	-0.259
13	Electrical and Optical Equipment	0.120	0.082	0.050	-0.319	-0.392
14	Transport Equipment	0.125	0.089	0.071	-0.292	-0.203
15	Manufacturing NEC; Recycling	0.236	0.143	0.084	-0.394	-0.413
16	Electricity, Gas and Water Supply	0.450	0.495	1.364	0.099	1.756
17	Construction	0.080	0.028	0.028	-0.652	-0.010
18	Sale, Maintenance and Repair of Motor Vehicles and Motorcycles; Retail Sale of Fuel	0.057	0.049	0.061	-0.140	0.262
19	Wholesale Trade and Commission Trade	0.057	0.049	0.062	-0.140	0.280

20	Retail Trade; Repair of Household Goods	0.068	0.056	0.073	-0.175	0.287
21	Hotels and Restaurants	0.478	0.191	0.144	-0.600	-0.248
22	Transport and Storage	0.161	0.167	0.514	0.041	2.070
23	Post and Telecommunications	0.028	0.024	0.040	-0.138	0.650
24	Financial Intermediation	0.038	0.014	0.014	-0.638	0.026
25	Real Estate Activities	0.018	0.042	0.078	1.389	0.864
26	Renting of M&Eq and Other Business Activities	0.046	0.015	0.012	-0.666	-0.250
27	Public Admin and Defense; Social Security	0.045	0.039	0.048	-0.122	0.231
28	Education	0.060	0.024	0.040	-0.595	0.645
29	Health and Social Work	0.282	0.055	0.036	-0.805	-0.345
30	Other Community, Social And Personal Services	0.100	0.061	0.070	-0.387	0.138

On average the most energy intensive industry is found to be the Coke, refined petroleum and nuclear fuel industry (code 7), followed by Chemicals and chemical products industry (code 8). In the other hand, the least energy intensive industries on average are Financial intermediation (code 24), Renting of machinery and equipment and other business activities (code 26), and Post and telecommunications industry (code 23).

There was a steady decline in energy intensity in all industries during 1990s except for three industries Coke, refined petroleum and nuclear fuel industry (code 7), Electricity, gas and water supply (code 16), and Real estate activities (code 25) during 1990s. However, most of them have again increased during 2000s. A number of 19 industries out of 30 have increased in its energy intensity in the last decade.

The decline in the energy consumption in that period was mainly due to introduction of new technology that allowed for some industries to produce their output with less energy input (B. C. Kim & Labys, 1988). The main reason for the dramatic increase in the energy intensity by 22.5% during 2000s is the rapid economic development of the South Korean economy, as it shifted to be characterized as an industrialized country. As a result, industries with high intensity of energy use have grown rapidly due to structural changes in the South Korean economy.

Chapter 5: Effects of ICT Investment on Energy Use: A Comparative Study between South Korea and Japan

This chapter examines productivity changes in Japan and South Korea during 1973–2006 and 1980–2009, respectively, in order to assess how investment in ICT capital affects energy demand. A dynamic factor demand model is applied to link inter-temporal production decisions by explicitly recognizing that the level of certain factors of production (refer to as quasi-fixed factors) cannot be changed without incurring the so-called adjustment costs, defined in terms of forgone output from current production. Hence, this chapter quantifies how ICT capital investment in South Korea and Japan affects economic growth in general and industrial energy demand in particular.

5.1 Introduction

The ICT revolution of the mid-1990s is considered to be the main driver of the new global economy. Evidence shows that ICT has a strong potential to continue to influence the economic growth (Atkinson & McKay, 2007; Takase & Murota, 2004). This noticeable effect of ICT is similar to the general-purpose technology that emerged from the Industrial Revolution in the nineteenth century (Hatch & Mackey, 2002). In particular, the impact of ICT capital investment on energy demand is considerable. However, although the use of ICT is associated with the rises in energy consumption and greater greenhouse gas emission (Seungdo, Hyeon-Kyeong, & Hyoung-Jun, 2009;

Takase & Murota, 2004), a report by the Global e-Sustainable Initiative (GeSI) predicted that ICT use will reduce global greenhouse gas emission by 16.5% over the next decade (GeSI SMARTer 2020, 2012).

ICT investment has grown at a rapid rate in Japan since 1980, and in South Korea since 1990. Nevertheless, in a study conducted by Lu, Lin, and Lewis (2007), South Korea CO2 emission from 1990 to 2002 were almost double those of Japan (42.40 million metric tons versus 24.20 million metric tons of aggregate emissions). This discrepancy suggests that the economic growth that occurred in parallel with the ICT development has either merely coincidental or has had no effect on the energy supply and demand structure. However, few studies have thus far considered the link between ICT investment and energy consumption (Y. Cho et al., 2007). To that end, this chapter investigates whether ICT capital investment influences energy demand. In particular, it empirically examines the industrial productivity changes in Japan and South Korea during 1973–2006 and 1980–2009, respectively, by applying and extending the dynamic factor demand model proposed by Nadiri and Prucha (2001).

The model used in this study is a remarkably flexible framework capable of providing an extensive set of observations. The model has firstly developed in a series of papers by Nadiri and Prucha (Nadiri & Prucha, 1986, 1990, 1996, 1999, 2001) to estimate firms' demand for quasi-fixed and variable input factors of production. This study applies the model suggested by Nadiri and Prucha (2001) to investigate the Japanese and the South Korean industrial sectors for the periods 1973–2006 and 1980–2009, respectively.

According to the framework developed by the above authors, the firms in the concerned industries maximize the present value of their future profit streams, choosing their level of output, and determining the optimal input levels of energy, ICT capital, and other input factors of production accordingly. Nadiri and Prucha (2001) recommended this calculation for each period in the light of newly available information. Firms and industries in the short-run use both quasi-fixed (ICT capital and non-ICT capital) and variable (labor, materials, and energy) inputs. Variable inputs will be fully adjusted from one period to another, while quasi-fixed inputs will be adjusted partially, since adjusting them fully is costly. Thus, firms do not immediately jump to the long-run equilibrium level of quasi-fixed inputs.

The econometric estimation, particularly the sensitivity analysis of input demands with respect to factor prices measured through both short- and long-run price elasticities, provide a rich set of information on the production process. Price elasticities can be used to investigate, for example, how much energy demand changes when energy prices increase. When energy prices rise, industries will tend to economize on energy use. The reaction to a potentially permanent rise in energy prices will possibly be less in the immediate future than in the long run. The industry’s technological features are captured by economies of scale measures, and degrees of substitutability between different input factors of production. Economies of scale indicate whether output can be expanded at constant, increasing, or decreasing average unit costs. The substitutability of inputs reveals to what level capital investment can, for example, reduce energy use or hours of labor per unit of output.

This chapter is especially concerned with the possible substitutability of ICT capital investment for energy demand. The relationship between ICT capital investment and energy use has been extensively studied (For a survey of more recent studies, see: Sadorsky, 2012). The two oil price shocks in the 1970s have redirected the general interest into how to reduce energy consumption in economies by adopting a greater usage of ICT (Walker, 1985, 1986).

Recent studies have shown that ICT and energy are substitutes (see for example:Campos Marchado & Miller, 1997; X. Chen, 1994; Khayyat, 2013; Sadorsky, 2012; Watanabe et al., 2005). In another example, Y. Cho et al. (2007) studied the impact of ICT investment and energy price on electricity consumption in South Korea's industrial sector. They explained the electricity consumption pattern based on the concept of electricity intensity. Using the logistic growth model they found that ICT reduces the demand for electricity in some manufacturing sectors.

Scholars applied different specifications to model production, cost, and energy demand, or a combination thereof, depending on whether the objective is cost minimization or output maximization. In their empirical analysis, different studies utilize data on diverse countries, regions, and industrial sectors. A few studies use firm-levels data. The results, in general, indicate substitution between capital and energy, although complementarity between energy and capital is also frequently observed. The degree of substitutability and complementarity differ significantly according to data dimensions and unit characteristics. This study expands the dynamic factor demand models proposed by Nadiri and Prucha (2001) using materials, energy, and labor as variable inputs and distinguishing between ICT and non-ICT capital.

5.2 Theoretical Model and Empirical Specification

Consider a firm or industry that employs *m* variable inputs and *n* quasi-fixed inputs to produce a single output from a technology with internal adjustment costs. In line with Nadiri and Prucha (1990), its production process can be described by the following generalized production function:

$$(1) \qquad Y_{i,t} = F\left(V_{i,t}, X_{i,t-1}, \Delta X_{i,t}, T_{i,t}\right)$$

Where, the subscripts ($i=1,2,\ldots$) and ($t=1,2,\ldots$) represent industry and time respectively, Y_{it} denotes gross output, V_{it} is a vector of variable inputs, X_{it} is a vector of quasi-fixed inputs, $\Delta X_{it} = X_{it} - X_{it-1}$ is a vector representing the internalization of the adjustment costs into the production function in terms of the foregone output, due to changes in the stock of quasi-fixed inputs, and T_{it} is an exogenous technology index. The function F is assumed to be twice continuously differentiable, and $\partial F/\partial v_{it} > 0$, $\partial F/\partial x_{it-1} > 0$, and $\partial F/\partial \Delta x_{it} < 0$. In addition, F is to be strictly concave in all arguments, except possibly for the technology index. A change in the levels of the quasi-fixed factors will result in adjustment costs due to the resource allocation required to change the input stock rather than produce additional output.

The duality principle in production theory indicates that given a production function, under the appropriate regularity conditions, it is possible to derive a unique corresponding firm's total minimum cost function *C(w,Y)* as the solution to the problem of minimizing the cost of producing a specified level of output as follows:

(2) $$C(w,Y) = \left\{ \min_{x} xw : f(x) \geq Y \right\}$$

where x is a vector of input quantities and w is a vector of input prices. The cost function *C(.)* should validate the regularity conditions, i.e. to be concave, non-decreasing, continuous function of w, and positive homogeneous of degree one.

The production structure can then be described equivalently in terms of a restricted cost function. A perfectly competitive factor input market for the industry should be assumed. The acquisition prices for the variable and quasi-fixed inputs are denoted as $\hat{p}_t^{V_i} (i = 1, 2, \ldots, m)$ and $\hat{p}_t^{X_i} (i = 1,2, \ldots, n)$ respectively. All prices can be normalized to the price of the first variable factor. Normalizing the variable production cost and the factor price of inputs by the first input price will impose the condition of homogeneity of degree one in the input prices on the variable cost function (Nadiri, 1993). In addition to that this procedure has been found convenient which avoid the model to suffer from singularity problems. The normalized prices are denoted as $p_t^{V_j} = \hat{p}_t^{V_i}/\hat{p}_t^{V_1}$ and $p_t^{X_j} = \hat{p}_t^{X_i}/\hat{p}_t^{V_1}$, $(j = 1,2, \ldots, m)$. The normalized restricted cost function is then defined as follows:

(3) $$G\left(p_{i,t}^{V_j}, X_{i,t-1}, \Delta X_{i,t}, Y_{i,t}, T_{i,t}\right) = \sum_{j=1}^{m} \hat{p}_{i,t}^{V_j} \hat{V}_{i,jt}$$

where $\hat{V}_{jt}$ denotes the cost-minimizing amounts of variable inputs required to produce the output Y conditional on $X_{i,t-1}$ and $\Delta X_{i,t}$. The normalized restricted cost function *G(.)* assumed to be convex in $X_{i,t-1}$ and $X_{i,t}$, and concave in $\mathrm{p}_{\mathrm{t}}^{\mathrm{V}}$ (Lau, 1986).

The normalized restricted cost function *G(.)* is a short-run cost function. As depicted by Jehle and Reny (2001), when the firm is constrained, in the short-run, by a fixed amount of specific inputs for its production, it cannot freely select the optimal amount, so that the short- and long-run costs will differ. The firm's cost in period *t* is specified as follows:

$$(4) \qquad C\big(X_{i,t}, X_{i,t-1}, \Omega_{i,t}\big) = G\big(p_{i,t}^{V}, X_{i,t-1}, \Delta X_{i,t}, Y_{i,t}, T_{i,t}\big) + \textstyle\sum_{h=1}^{n} p_{i,t}^{X_i} I_{h,t}$$

where $\Omega_{i,t}$is a vector composed of $\mathrm{p}_{\mathrm{i,t}}^{\mathrm{V}_j}, \mathrm{p}_{\mathrm{i,t}}^{\mathrm{X}_j}, Y_{i,t}$ and $T_{i,t}$. The real investment of the h^{th} quasi-fixed input is defined as follows:

$$(5) \qquad I_{ht} = X_{ht} - (1 - \delta_h)X_{ht-1}$$

where δ_h denotes the depreciation rate of the stock of the h^{th} quasi-fixed input.

The dynamic problem facing the firm is assumed to minimize the expected present value of current and future costs given the initial values of quasi-fixed inputs. The firm's optimization problem can be classified by regarding the length of the planning horizon into finite and infinite planning horizon. Consider the case of infinite planning horizon, in this case the firm's objective function in period *t* is defined as follows:

$$(6) \qquad \textstyle\sum_{\mathrm{t=0}}^{\infty} C\big(\mathrm{X_{i,t}}, \mathrm{X_{i,t-1,}}, \mathrm{E}\Omega_{\mathrm{i,t}}\big)(1 + \mathrm{r})^{-\mathrm{t}}$$

where *E* denotes the expectations operator conditional on information available at the beginning of period *t*, and *r* is the real interest rate. The firm in each period *t* derives an optimal plan for the quasi-fixed inputs for period *t*, *t*

+ 1, … such that equation (6) is minimized subject to the initial stock X_{t-1}, and then chooses its quasi-fixed inputs in period t according to this plan. In each period the firm will only implement a portion of its optimal input plan. This process is repeated every period, in which a new optimal plan is formulated as new information to the exogenous variables is available, and expectations on those variables are modified accordingly. In the case of a finite but shifting planning horizon, where the stock of quasi-fixed inputs at the end of the planning horizon is assumed to be determined endogenously subject to the assumption of static expectations. However, the optimal plans for the finite horizon model converges rapidly to those of the infinite planning horizon model as the planning horizon extends (Nadiri & Prucha, 1990). Accordingly, this study assumes the optimal plans for the infinite planning horizon.

The model is specified to employ the optimal levels of the variable inputs of materials (M), energy (E), and labor (L), as well as the quasi-fixed inputs of ICT capital (ICT) and non-ICT capital (K). It is assumed that the variable inputs can be adjusted instantaneously in response to a change in relative input prices. The adjustment of the capital stock in response to changes in relative input prices will be slow. The following dynamic cost function is solved with respect to the quasi-fixed factors with non-static expectation:

(7)

$$\min_{K_{t+\tau},ICT_{t+\tau}} \sum_{\tau=1}^{\infty}[G(p_{i,t}^{L}, p_{i,t}^{E}, K_{i,t+\tau-1}, ICT_{i,t+\tau-1}, \Delta K_{i,t+\tau}, \Delta ICT_{i,t+\tau}, Y_{i,t+\tau}, T_{i,t+\tau}) + p_{i,t}^{K} I_{i,t+\tau,} + p_{i,t}^{ICT} H_{i,t+\tau}](1+r_t)^{-\tau}$$

Subjects to:

$$I_{i,t+\tau} = K_{i,t+\tau} - (1-\delta)K_{i,t+\tau-1}$$

$$H_{i,t+\tau} = ICT_{i,t+\tau} - (1-\mu)ICT_{i,t+\tau-1}$$

where p^E, p^L, p^{ICT}, and p^K are prices for E, L, ICT, and K normalized by the price of M, respectively [8]. H and I are the real investment in ICT capital and non-ICT capital, respectively. The depreciation rates of ICT and non-ICT capital are μ and δ, respectively, and r denotes the discount rate.

It is necessary to introduce the concept of the certainty-equivalent principle before solving the non-stochastic dynamic control problem described in equation (7). As defined by Benth, Cartea, and Kiesel (2008), and Ljungqvist and Sargent (2004), the principle of certainty equivalence is the decision rule to solve the stochastic optimal linear regulator problem, which is equivalent to the decision rule for the non-stochastic linear optimal regulator problem. Furthermore, the principle is considered as a special property of the optimal linear regulator problem derived from the quadratic objective function, the linear transition equation, and the property $E(\varepsilon_{t+1}|x_t) = 0$. Hence, it can be inferred from the above that the optimal input paths in period t that correspond to the stochastic control problem are equivalent to those obtained through certainty equivalence. Then, the non-stochastic dynamic control problem is assumed to be solved as *G(.)* in a quadratic form (Robles, 1995).

The normalized restricted cost function *G(.)* in a quadratic form, as introduced by Denny, Fuss, and Waverman (1981), can be described as follows:

[8] The materials input price is considered as *numeraire*.

(8) $G\left(p_{i,t}^{L}, p_{i,t}^{E}, K_{i,t-1}, ICT_{i,t-1}, \Delta K_{i,t}, \Delta ICT_{i,t}, Y_{i,t}, T_{i,t}\right) = M_{i,t} + p_{i,t}^{L} L_{i,t} + p_{i,t}^{E} E_{i,t} = \Big[a_0 + a_l p_{i,t}^{L} + a_e p_{i,t}^{E} + a_T T_{i,t} + a_{Tl} T_{i,t} p_{i,t}^{L} + a_{Te} T_{i,t} p_{i,t}^{E} + a_{el} p_{i,t}^{L} p_{i,t}^{E} + \frac{1}{2} a_{ll} \left(p_{i,t}^{L}\right)^2 + \frac{1}{2} a_{ee} \left(p_{i,t}^{E}\right)^2\Big] Y_{i,t} + a_K K_{i,t-1} + a_{ICT} ICT_{i,t-1} + \left[\frac{1}{2} a_{KK} \mathrm{K}_{i,t-1}^2 + \frac{1}{2} a_{ICTICT} \mathrm{ICT}_{i,t-1}^2 + \frac{1}{2} a_{\dot{K}\dot{K}} \Delta \mathrm{K}_{i,t}^2 + \frac{1}{2} a_{I\dot{C}TI\dot{C}T} \Delta \mathrm{ICT}_{i,t}^2\right] \frac{1}{Y_{i,t}} + a_{lK} p_{i,t}^{L} K_{i,t-1} + a_{lICT} p_{i,t}^{L} ICT_{i,t-1} + a_{eK} p_{i,t}^{E} K_{i,t-1} + a_{eICT} p_{i,t}^{E} ICT_{i,t-1} + a_{TK} K_{i,t-1} T_{i,t} + a_{TICT} ICT_{i,t-1} T_{i,t}$

The normalized restricted cost function described in equation (8) displays a linearly homogeneous technology that can be described in a generalized form as follows:

(9) $G\left(p_{i,t}^{L}, p_{i,t}^{E}, \frac{K_{i,t-1}}{Y_{i,t}}, \frac{ICT_{i,t-1}}{Y_{i,t}}, \frac{\Delta K_{i,t}}{Y_{i,t}}, \frac{\Delta ICT_{i,t}}{Y_{i,t}}, T_{i,t}\right) Y_{i,t}$

The marginal adjustment cost needs to be equal to zero in the steady state of quasi-fixed inputs when *ΔK* and *ΔICT* are equal to zero. Hence, $\partial G(.)/\partial \Delta K = 0$ and $\partial G(.)/\partial \Delta ICT = 0$ will be zero at *ΔK* = *ΔICT* = 0 only if the following restrictions are imposed on the estimated parameters (Denny et al., 1981):

(10) $a_{\dot{K}} = a_{I\dot{C}T} = a_{l\dot{K}} = a_{lI\dot{C}T} = a_{K\dot{K}} = a_{ICTI\dot{C}T} = a_{\dot{K}I\dot{C}T} = a_{ICT\dot{K}} = a_{T\dot{K}} = a_{TI\dot{C}T} = 0$

where a dot over a variable represents the growth rate in the quasi fixed inputs.

Imposing the separability assumption, as recommend by Nadiri and Prucha (1990), on the quasi-fixed inputs will simplify the derivation of the dynamic factor demand model. In this study, separability of the quasi-fixed input implies that $a_{KICT} = a_{\dot{K}I\dot{C}T}$. The convexity and concavity conditions of the normalized restricted cost function under the separability assumption imply that a_{KK}, a_{ICTICT}, $a_{\dot{K}\dot{K}}$, $a_{I\dot{C}TI\dot{C}T} > 0$ and $a_{ll}, a_{ee} < 0$. The optimal input paths of investment in ICT and non-ICT-capital must satisfy the necessary conditions given by the Euler equations (Toro, 2009), obtained by solving equation (7) with respect to K and ICT as follows:

(11) $-a_{\dot{K}\dot{K}}K_{i,t+\tau+1} + [a_{\dot{K}\dot{K}} + (2 + r_t)a_{\dot{K}\dot{K}}]K_{i,t+\tau} - (1 + r_t)a_{\dot{K}\dot{K}}K_{i,t+\tau-1} = -\left((1-\delta)p_{i,t}^{K} + a_K + a_{lK}p_{i,t}^{L} + a_{eK}p_{i,t}^{E} + a_{TK}T_{i,t}\right)Y_{i,t}$

(12) $-a_{I\dot{C}TI\dot{C}T}ICT_{i,t+\tau+1} + [a_{I\dot{C}TI\dot{C}T} + (2 + r_t)a_{I\dot{C}TI\dot{C}T}]ICT_{i,t+\tau} - (1 + r_t)a_{I\dot{C}TI\dot{C}T}ICT_{i,t+\tau-1} = -\left((1-\mu)p_{i,t}^{ICT} + a_{ICT} + a_{lICT}p_{i,t}^{L} + a_{eICT}p_{i,t}^{E} + a_{TICT}T_{i,t}\right)Y_{i,t}$

The transversality conditions below will rule out the unstable roots for the Euler equations:

$\lim_{n\to\infty}(1 + r_\tau)^\tau \left(a_{\dot{K}\dot{K}}K_{i,t+\tau} - a_{\dot{K}\dot{K}}K_{i,t+\tau-1}\right) = 0$, and,

$\lim_{n\to\infty}(1 + r_\tau)^\tau \left(a_{I\dot{C}TI\dot{C}T}\mathrm{ICT}_{i,t+\tau} - a_{I\dot{C}TI\dot{C}T}\mathrm{ICT}_{i,t+\tau-1}\right) = 0$,

The accelerator equations as described by Nadiri and Prucha (1990) serve as a solution corresponding to the stable roots for the Euler equations as follows:

(13.1) $\Delta K_{i,t} = m_{KK}\left(K_{i,t}^{*} - K_{i,t-1}\right)$

(13.2) $\Delta ICT_{i,t} = m_{ICTICT}\left(ICT_{i,t}^{*} - ICT_{i,t-1}\right)$

(13.3) $m_{KK} = -\frac{1}{2}\left[(r_t + a_{KK}/a_{\dot{K}\dot{K}}) - ((r_t + a_{KK}/a_{\dot{K}\dot{K}})^2 + 4\, a_{KK}/a_{\dot{K}\dot{K}})^{1/2}\right]$

(13.4) $m_{ICTICT} = -\frac{1}{2}\left[(r_t + a_{ICTICT}/a_{I\dot{C}TI\dot{C}T}) - ((r_t + a_{ICTICT}/a_{I\dot{C}TI\dot{C}T})^2 + 4\, a_{ICTICT}/a_{I\dot{C}TI\dot{C}T})^{1/2}\right]$

(13.5) $K^*_{i,t} = -\frac{1}{a_{KK}}\left[(r_t + \delta)p^K_{i,t} + a_K + a_{lK}p^L_{i,t} + a_{eK}p^E_{i,t} + a_{TK}T_{i,t}\right]Y_{i,t}$

(13.6) $ICT^*_{i,t} = -\frac{1}{a_{ICTICT}}\left[(r_t + \mu)p^{ICT}_{i,t} + a_{ICT} + a_{lICT}p^L_{i,t} + a_{eICT}p^E_{i,t} + a_{TICT}T_{i,t}\right]Y_{i,t}$

Substituting the steady solutions of the Euler equations (11) and (12), and the adjustment coefficient forms (13.3) and (13.4) into the accelerator coefficients (13.1) and (13.2), respectively, in line with Nadiri and Prucha (1990), it gives the optimal quasi-fixed input path for ICT and non-ICT capital as follows:

(14) $\Delta K_{i,t} = (-\frac{1}{2}\left[(r_t + a_{KK}/a_{\dot{K}\dot{K}}) - ((r_t + a_{KK}/a_{\dot{K}\dot{K}})^2 + 4\, a_{KK}/a_{\dot{K}\dot{K}})^{1/2}\right]) * \left(-\frac{1}{\mathrm{a_{KK}}}\left[(\mathrm{r_t} + \delta)\mathrm{p^K_{i,t}} + \mathrm{a_K} + \mathrm{a_{lK}p^L_{i,t}} + \mathrm{a_{eK}p^E_{i,t}} + \mathrm{a_{TK}T_{i,t}}\right]\mathrm{Y_{i,t}} - \mathrm{K_{i,t-1}}\right)$

(15) $\Delta ICT_{i,t} = (-\frac{1}{2}\left[(r_t + a_{ICTICT}/a_{I\dot{C}TI\dot{C}T}) - ((r_t + a_{ICTICT}/a_{I\dot{C}TI\dot{C}T})^2 + 4\, a_{ICTICT}/a_{I\dot{C}TI\dot{C}T})^{1/2}\right]) * \left(-\frac{1}{a_{ICTICT}}\left[(r_t + \mu)p^{ICT}_{i,t} + a_{ICT} + a_{lICT}p^L_{i,t} + a_{eICT}p^E_{i,t} + a_{TICT}T_{i,t}\right]Y_{i,t} - ICT_{i,t-1}\right)$

By Shephard's lemma (Shephard, 1953), the variable input demand equations for *L*, *E*, and *M* can be obtained as follows:

(16) $L_{i,t} = \frac{\partial G(.)}{\partial p_{i,t}^L} = \left(a_l + a_{ll} p_{i,t}^L + a_{el} p_{i,t}^E + a_{lT} T_{i,t}\right) Y_{i,t} + a_{lK} K_{i,t-1} + a_{lICT} ICT_{i,t-1}$

(17) $E_{i,t} = \frac{\partial G(.)}{\partial p_{i,t}^E} = \left(a_e + a_{ee} p_{i,t}^E + a_{el} p_{i,t}^L + a_{eT} T_{i,t}\right) Y_{i,t} + a_{eK} K_{i,t-1} + a_{eICT} ICT_{i,t-1}$

From $G(.) = M_{i,t} + p_{i,t}^L L_{i,t} + p_{i,t}^E E_{i,t}$, the demand equation for *M* is described as follows:

(18) $M_{i,t} = G(.) - p_{i,t}^L L_{i,t} - p_{i,t}^E E_{i,t} = \left[a_0 + a_T T_{i,t} - \frac{1}{2} a_{ll} \left(p_{i,t}^L\right)^2 - \frac{1}{2} a_{ee} \left(p_{i,t}^E\right)^2 - a_{el} p_{i,t}^L p_{i,t}^E\right] Y_{i,t} + a_K K_{i,t-1} + a_{ICT} ICT_{i,t-1} + \left[\frac{1}{2} a_{KK} \mathrm{K}_{i,t-1}^2 + \frac{1}{2} a_{ICTICT} \mathrm{ICT}_{i,t-1}^2 + \frac{1}{2} a_{\dot{K}\dot{K}} \Delta \mathrm{K}_{i,t}^2 + \frac{1}{2} a_{I\dot{C}TI\dot{C}T} \Delta \mathrm{ICT}_{i,t}^2\right] \frac{1}{Y_{i,t}} + \mathrm{a_{TK} K_{i,t-1} T_{i,t}} + \mathrm{a_{TICT} ICT_{i,t-1} T_{i,t}}$

The firm's decision hence is represented given an explicit form for the variable cost function *G(.)* by a system of demand equations and investment equations for the quasi-fixed input, incorporating non-static expectations. The demand equations for the quasi-fixed factors are in the form of accelerator model, while the industry's variable inputs are directly derived from the restricted cost function via shepherd's lemma. The entire system of equations to be estimated consists of the two quasi-fixed input and three variable input, i.e. equations (14) to (18). The industry dummy variables and a stochastic error term is added to each equation in order to capture the industry fixed effects and random errors in cost minimization problem, respectively.

The system of equations is non-linear in both parameters and variables; therefore, it needs to be estimated by using non-linear estimation method. The model follows Nadiri and Prucha (1996) by allowing for first order autocorrelation in the residuals. The estimated autocorrelation coefficients are close to unity. The standard error are computed from a numerical estimate of the Hussein. Thus, the model parameters are estimates by using the Full Information Maximum Likelihood (FIML) method with the SAS 9.3 application package.

5.3 Parameters Estimates

The system equations include dummy variables for industry and industry-specific characteristics. These dummy variables capture industry-specific effects (Fixed Effect approach due to presence of panel data) because of the heterogeneity across industries that cannot be explained by the production structure alone. The variance-covariance estimator used for FIML is a generalized least-square estimator. The generalized least-squares approximation to the Hessian is used in the minimization procedure.

The two sample periods have been divided into three sub-periods: 1980–1989, 1990–1999, and 2000–2009 for South Korea, and 1974–1984, 1985–1995, and 1996–2006 for Japan[9]. In addition, both samples are divided into knowledge-based and non-knowledge-based industries. The parameter estimates reported in Table 5.1 and Table 5.2 for South Korea and Japan, respectively, satisfy the conditions of convexity of the normalized restricted cost function in ICT capital and non-ICT capital, and concavity in the variable input prices.

[9] The aim is to reflect the structural changes in the Korean economy due to the implementation of economic development plan explained in chapter 2.

The parameter estimates $a_{KK}, a_{\dot{K}\dot{K}}, a_{ICTICT}$, and $a_{I\dot{C}TI\dot{C}T}$ are positive while a_{ll} and a_{ee} are negative. The hypothesis of the absence of adjustment costs for the quasi-fixed inputs ICT capital and non-ICT capital, $a_{\dot{K}\dot{K}} = 0$ and $a_{I\dot{C}TI\dot{C}T} = 0$, are rejected. Hence, the static equilibrium model is inappropriate to describe the technology and the structure of the factor demand of the industrial sector for South Korea and Japan. The demand for the variable inputs depends negatively on their own normalized prices. The negative signs of the quasi-fixed inputs ICT capital and non-ICT capital in both labor and energy demand functions indicate that both ICT capital and non-ICT capital are substitutes for the labor and energy inputs. The positive sign of the technology index parameter in the labor demand function implies a decreasing productivity of the labor input. The significance of the industry dummy variables coefficients imply significant differences in the cost structure across industries[10].

The parameter estimates per se are difficult to interpret. Consequently in the following sections, estimates for various implied characteristics for the estimated factor demand systems are presented.

[10] The estimated coefficients for the industries' dummy variables are not reported to save space.

Table 5. 1

Non-linear FIML Estimates-Dynamic Factor Demand, Korea 30 sectors (1980-2009)

	1980–1989		**1990–1999**		**2000–2009**		**Knowledge Based**		**Non-Knowledge Based**	
Parameter	**Estimate**	**t Value**	**Estimate**	**t Value**	**Estimate**	**t Value**	**Estimate**	**t Value**	**Estimate**	**t Value**
$\mathbf{a_{kk}}$	0.073***	6.390	0.085***	11.880	0.066***	7.440	0.039***	6.850	0.094***	14.640
	(0.011)		(0.007)		(0.009)		(0.006)		(0.006)	
$\mathbf{a_{koko}}$	2.522***	5.910	1.506***	9.820	1.848***	7.640	1.382***	8.920	1.365***	13.370
	(0.427)		(0.153)		(0.242)		(0.155)		(0.102)	
$\mathbf{a_{k}}$	-0.142***	-4.030	-0.169***	-11.880	-0.078***	-7.120	-0.163***	-9.130	-0.101***	-9.010
	(0.035)		(0.014)		(0.11)		(0.018)		(0.011)	
$\mathbf{a_{lk}}$	-0.048***	-3.080	-0.037***	-4.880	0.000	-0.040	-0.016**	-2.110	-0.021***	-5.510
	(0.016)		(0.008)		(0.008)		(0.007)		(0.004)	
$\mathbf{a_{ek}}$	-0.040***	-2.430	-0.055***	-7.870	-0.034***	-9.160	-0.046***	-10.180	-0.026***	-8.510
	(0.017)		(0.007)		(0.004)		(0.005)		(0.003)	
$\mathbf{a_{tk}}$	-0.001	-0.320	0.002**	1.700	-0.002**	-2.530	0.004***	8.220	-0.002***	-5.410

	(0.003)		(0.001)		(0.001)		(0.0001)		(0.000)	
a_{ii}	0.201***	7.930	0.169***	9.650	0.105***	14.750	0.119***	10.800	0.143***	21.340
	(0.025)		(0.018)		(0.007)		(0.011)		(0.007)	
a_{ioio}	15.300***	7.400	0.826***	11.950	1.283***	10.250	2.033***	9.020	0.963***	20.010
	(0.066)		(0.069)		(0.125)		(0.225)		(0.048)	
a_i	-0.225***	-3.860	-0.259***	-12.430	-0.123***	-10.970	-0.292***	-9.610	-0.118***	-12.000
	(0.058)		(0.021)		(0.011)		(0.030)		(0.010)	
a_{li}	-0.094***	-3.350	-0.083***	-5.620	-0.013	-1.240	-0.033**	-1.670	-0.051***	-8.480
	(0.028)		(0.015)		(0.011)		(0.020)		(0.006)	
a_{ei}	-0.059**	-1.920	-0.085***	-9.700	-0.059***	-12.090	-0.071***	-6.300	-0.056***	-13.570
	(0.031)		(0.009)		(0.005)		(0.011)		(0.004)	
a_{ti}	-0.008	-1.470	0.002*	0.860	-0.007***	-5.090	0.005***	4.430	-0.005***	-9.220
	(0.005)		(0.002)		(0.001)		(0.001)		(0.001)	
a_l	0.993***	5.100	1.423***	6.510	0.735***	2.810	1.269***	3.160	0.226	0.880
	(0.195)		(0.219)		(0.262)		(0.201)		(0.256)	
a_{ll}	-0.361***	-9.140	-0.036***	-3.580	-0.023*	-1.620	-0.018	-1.130	-0.008*	-1.470

	(0.040)		(0.010)		(0.014)		(0.016)		(0.006)	
a_{el}	0.204***	6.990	0.031***	4.070	0.005	0.700	0.009	0.990	0.005*	1.630
	(0.029)		(0.008)		(0.007)		(0.009)		(0.003)	
a_{lt}	0.003	0.140	-0.045	-1.490	0.043	1.510	-0.015	-0.920	0.037***	4.010
	(0.024)		(0.030)		(0.029)		(0.016)		(0.009)	
a_e	0.922***	8.450	0.966***	16.960	0.917***	15.890	1.338***	8.690	0.744***	20.220
	(0.109)		(0.057)		(0.058)		(0.154)		(0.037)	
a_{ee}	-0.120***	-3.350	-0.014**	-2.160	0.012***	3.080	-0.015**	-2.020	0.000	-0.170
	(0.036)		(0.006)		(0.004)		(0.007)		(0.002)	
a_{et}	-0.023**	-2.100	0.008*	1.190	0.003	0.490	-0.021***	-3.850	0.006***	4.330
	(0.011)		(0.007)		(0.006)		(0.005)		(0.001)	
a_0	1.067***	4.420	1.122***	17.770	0.901***	15.080	1.505***	9.340	0.758***	17.440
	(0.241)		(0.063)		(0.060)		(0.161)		(0.043)	
a_t	-0.006	-0.190	0.007	0.830	0.008	1.260	-0.027***	-4.810	0.012***	7.170
	(0.030)		(0.008)		(0.006)		(0.006)		(0.002)	
Log Likelihood		**1054**	**634.01**		**470.81**		**155.9**		**685.1**	

Table 5. 2

Non-linear FIML Estimates-Dynamic Factor Demand, Japan 30 sectors (1973–2007)

	1973–1982		1983–1999		2000–2007		Knowledge Based		Non-Knowledge Based	
Parameter	**Estimate**	**t Value**	**Estimate**	**t Value**	**Estimate**	**t Value**	**Estimate**	**t Value**	**Estimate**	**t Value**
a_{kk}	0.128***	6.990	0.175***	14.700	0.068***	6.280	0.122***	9.080	0.128***	13.510
	(0.018)		(0.012)		(0.011)		(0.013)		(0.010)	
a_{koko}	1.372***	7.150	0.736***	8.240	3.082***	6.200	1.383***	5.490	1.991***	9.780
	(0.192)		(0.089)		(0.497)		(0.252)		(0.204)	
a_{k}	-0.105***	-4.720	-0.162***	-12.630	-0.059***	-3.930	-0.134***	-6.750	-0.146***	-12.310
	(0.022)		(0.013)		(0.015)		(0.020)		(0.012)	
a_{lk}	-0.161***	-8.920	-0.119***	-7.460	-0.095***	-7.580	-0.131***	-7.400	-0.097***	-8.130
	(0.018)		(0.016)		(0.013)		(0.018)		(0.012)	
a_{ek}	-0.019*	-1.960	-0.024***	-3.300	-0.015*	-1.640	-0.030***	-3.000	-0.023***	-3.690
	(0.010)		(0.007)		(0.009)		(0.010)		(0.006)	
a_{tk}	0.000	0.130	-0.003***	-3.950	-0.001***	-2.760	0.002***	4.200	0.001**	1.800

	(0.001)		(0.001)		(0.000)		(0.000)		(0.000)	
a_{ii}	0.404***	16.340	0.116***	11.090	0.032***	14.940	0.052***	8.780	0.092***	20.420
	(0.025)		(0.010)		(0.002)		(0.006)		(0.005)	
a_{ioio}	4.955***	13.700	0.883***	14.870	0.041***	8.760	0.136***	7.010	0.070***	16.030
	(0.362)		(0.059)		(0.005)		(0.019)		(0.004)	
a_{i}	-0.275***	-9.860	-0.089***	-7.100	-0.042***	-5.620	-0.149***	-4.810	-0.062***	-4.860
	(0.028)		(0.013)		(0.007)		(0.031)		(0.013)	
a_{li}	-0.162***	-2.750	-0.198***	-9.930	-0.171***	-9.980	-0.271***	-9.410	-0.236***	-17.330
	(0.059)		(0.020)		(0.017)		(0.029)		(0.014)	
a_{ei}	0.047***	2.100	-0.020**	-2.200	0.016**	1.990	0.081***	8.330	0.024***	3.580
	(0.022)		(0.009)		(0.008)		(0.010)		(0.007)	
a_{ti}	0.004***	3.240	-0.002***	-5.030	-0.003***	-3.800	0.002**	2.380	-0.003***	-6.380
	(0.001)		(0.000)		(0.001)		(0.001)		(0.000)	
a_{l}	1.050***	19.570	1.144***	33.880	1.258***	30.820	0.959***	9.950	0.835***	25.610
	(0.054)		(0.034)		(0.041)		(0.097)		(0.033)	
a_{ll}	-0.067***	-2.810	0.015***	0.450	0.124***	4.250	0.152***	2.960	-0.115***	-6.490

	(0.024)		(0.034)		(0.029)		(0.051)		(0.018)	
a_{el}	0.040***	1.740	-0.008	-0.490	-0.079***	-4.430	-0.103***	-3.690	0.074***	6.250
	(0.023)		(0.016)		(0.018)		(0.028)		(0.012)	
a_{lt}	0.016***	2.780	0.021***	5.160	0.003	0.510	0.012***	3.100	0.020***	13.720
	(0.006)		(0.004)		(0.006)		(0.004)		(0.001)	
a_{e}	0.866***	12.770	1.137***	52.510	0.843***	16.790	1.555***	25.990	1.055***	42.930
	(0.068)		(0.022)				(0.060)		(0.025)	
a_{ee}	-0.030***	-1.780	0.001	0.110	0.035***	2.840	0.029*	1.520	-0.056***	-6.890
	(0.017)		(0.008)		(0.012)		(0.019)		(0.008)	
a_{et}	0.033***	3.830	-0.022***	-6.710	-0.008	-1.510	-0.032***	-13.330	-0.009***	-10.160
	(0.009)		(0.003)		(0.006)		(0.002)		(0.001)	
a_{0}	0.999***	14.730	1.204***	53.330	0.878***	19.110	1.488***	24.350	1.110***	42.380
	(0.068)		(0.023)		(0.046)		(0.061)		(0.026)	
a_{t}	0.031***	3.370	-0.018***	-5.020	-0.003	-0.520	-0.027***	-10.410	-0.006***	-5.070
	(0.009)		(0.004)		(0.005)		(0.003)		(0.001)	
Log Likelihood		**1848**	**2211**		**1070**		**535**		**1974**	

5.4 The Adjustment Speed

The estimated adjustment speed coefficients for the quasi-fixed inputs are reported in Table 5.3 and Table 5.4 for South Korea and Japan, respectively. The optimal paths for quasi-fixed inputs are described by the flexible accelerator equations, or the so-called partial adjustment coefficients in equations (13.3) and (13.4).

The adjustment coefficients explain the fraction of the gap between the initial stock and the respective long-run optimal values closed within one time period. In other words, in each period a portion of the difference between the initial stocks of these two capitals and the respective long run optimal values are closed. The partial adjustment is due to the cost of investment in capital. However, the long run optimal values are changing over time in response to changes in the variables exogenous to the firm's input decisions and changing market conditions (Morrison & Berndt, 1981; Nadiri & Prucha, 1990).

The stock of quasi-fixed inputs moves slowly toward the optimal value if the adjustment coefficient is close to zero and fast if the coefficient is close to one. These coefficients are essential in determining the investment patterns of the quasi-fixed factors. Omitting these terms will lead to misspecification of the investment patterns and inconsistency in estimates of the other technology parameters (Nadiri & Prucha, 1990).

Table 5. 3

Coefficients of Adjustment Speed (South Korea)

	1980–1989		1990–1999		2000–2009		Knowledge Based		Non-Knowledge Based	
	m_{kk}	m_{ictict}	m_{kk}	m_{ictict}	m_{kk}	m_{ictict}	m_{kk}	m_{ictict}	m_{kk}	m_{ictict}
Mean	0.131	0.084	0.188	0.341	0.16	0.238	0.134	0.195	0.211	0.301
Std Dev	0.004	0.004	0.005	0.005	0.002	0.002	0.007	0.007	0.007	0.007
Minimum	0.125	0.078	0.180	0.332	0.158	0.236	0.122	0.183	0.199	0.289
Maximum	0.135	0.087	0198	0.350	0.166	0.243	0.148	0.209	0.225	0.313

Table 5. 4

Coefficients of Adjustment Speed (Japan)

	1974-1984		1985-1995		1996-2006		Knowledge Based		Non-Knowledge Based	
	m_{kk}	m_{ictict}	m_{kk}	m_{ictict}	m_{kk}	m_{ictict}	m_{kk}	m_{ictict}	m_{kk}	m_{ictict}
Mean	0.239	0.224	0.371	0.29	0.137	0.577	0.243	0.445	0.211	0.657
Std Dev	0.006	0.006	0.006	0.006	0.001	0.001	0.011	0.009	0.011	0.007
Minimum	0.228	0.212	0.361	0.279	0.136	0.576	0.221	0.426	0.188	0.643
Maximum	0.248	0.233	0.381	0.3	0.138	0.577	0.255	0.455	0.223	0.665

The interpretation of the adjustment speed coefficients can be shown through an example. For South Korea, the coefficients of ICT and non-ICT capital for the sub-period 1980–1989 are 0.084 and 0.131, respectively. These figures imply that in the South Korean industries, approximately 8.4% and 13.1% of the gap between the optimal and actual stock of ICT and non-ICT capital, respectively, is closed within one year. Thus, the overall adjustment speed in the South Korean industries during the 1980s was faster for non-ICT than it was for ICT capital investment, although these adjustment processes do differ by industry. By contrast, the adjustment speed for ICT capital was faster than that for non-ICT capital during the second and third sub-periods (it tripled from the first to the second sub-periods and doubled in the third sub-period).

These results concur with the findings of M. Kim and Park (2009), who argued that technological flows across the industries that use ICT are positively related to time. The fast trend in the speed of ICT adjustment is due to the technological diffusion and strengthening the technology linkage across industries since 1990s. Moreover, high investment in ICT is partly due to the rapid decline in ICT capital prices, in which it made it possible for substituting between different types of capital goods. Furthermore, investment in the ICT capital might be driven by the perceived benefits that industries expect from ICT such as higher efficiency (López-Pueyo & Mancebón, 2010; Pilat & Lee, 2001).

For Japan, the adjustment speed for the ICT capital was slower than that for the non-ICT capital during the first and the second sub-periods, but this became faster in the third sub-period (1996–2006). The adjustment speed in the third sub-period was five times as fast as that in the second sub-period, agreeing with the findings of Kanamori and Motohashi (2007) and Fukao, Miyagawa, Mukai, Shinoda, and Tonogi (2009), who argued that ICT investment has become more feasible in Japan since the late 1990s given the contribution of ICT to the country's GDP growth.

For both countries, the ICT adjustment speed was faster in traditional industries than it was in the knowledge-based industries. Industries that have greater R&D expenditure tend to be ICT capital-intensive, and thus the gap between optimal and actual ICT capital investment is less than that in non-knowledge-based industries, which nevertheless aim to increase ICT use in the production process and strengthen the structured network among industries during the course of development.

5.5 Deviation from the Optimal Values

To provide some indications of the disequilibrium in the factor inputs from a long-run point of view, the average percentage difference of actual values from long-run optimal values for respective inputs (averaged over industries per decade and also based on knowledge and non-knowledge based industries) have been calculated and are given in Table 5.5. The long run optimal values for ICT capital (*ICT**) and non-ICT capital (*K**) are defined in equations (12.5) and (12.6). The long run optimal values of the variable inputs *L*, *E*, and *M* are obtained by substituting *ICT** and *K** in equations (15), (16), and (17) respectively. The percentage deviations are calculated as $100.(X_t\text{-}X_t{}^*)/X_t{}^*$, where *X* represents the vector of actual (observed) values of the input factors of production *L, M, E, ICT,* and *K*, and X^* represent the vector of the optimal values of *L, M, E, ICT,* and *K.*

For both countries, the non-ICT capital exceeds the long run optimal value and the reverse is true for ICT capital. At the beginning of the sample period the labor input was less than the optimal for South Korea, but then dramatically increased to exceed the optimal value, while for Japan, the labor was overused on average. Energy is over used only during the last sample period for South Korea. The gap between actual energy input and the long run optimal value are widened during the last period, indicating more energy consumption pattern in the South Korean industries is witnessed.

For Japan, energy was over used in all the periods under study. In general there are changes over time in the level to which actual and long run optimal values are different. There is a substantial decline in the gap for ICT capital during the last period of the sample for South Korea. The negative values for ICT capital indicate that the investment in ICT capital in both countries is less than optimal. There is opportunity for more investment in ICT to fill the gap from actual to its long-run optimal value. For South Korea, the gap between observed and optimal values of ICT capital for the non-knowledge based industries is less than that for the knowledge based industries, reflecting the faster adjustment speed figures presented in Table 5.3. The energy input is used more optimally in the knowledge based industries. This implies that investment in the ICT capital provided opportunity to lower the level of energy intensity in the industries with high technology level. For Japanese industries however, the energy input is over used in all periods and in both knowledge and non-knowledge based industries. The average percentage difference of actual values from the long-run optimal values for respective inputs for each individual South Korean industry is reported in Table 5.6.

Table 5. 5

Percentage Deviation of Actual Values from the Long-run Optimal Values

Years/Industry Type	**Capital**	**ICT**	**Labor**	**Materials**	**Energy**
			South Korea		
1981–1989	0.060	-0.465	-0.360	-0.190	-0.085
1990–1999	0.007	-0.533	0.964	-0.048	-0.023
2000–2009	0.051	-0.039	1.971	0.087	0.112
Knowledge Based	0.045	-0.312	0.75	-0.011	-0.008
Non- Knowledge Based	0.034	-0.403	0.98	-0.114	0.002
			Japan		
1974-1984	0.12	-0.312	0.368	0.12	0.18
1985-1995	0.163	-0.033	0.432	-0.346	0.42
1996-2006	0.213	-0.009	0.743	0.091	0.17
Knowledge Based	0.145	-0.169	0.323	0.004	0.238
Non- Knowledge Based	0.189	-0.089	0.681	-0.085	0.277

Table 5. 6

Percentage Deviation of Actual Value from the Long-Run Optimal Values by Industry-South Korea

Sector	Capital	ICT	Labor	Materials	Energy
Agriculture, Hunting, Forestry and Fishing	0.201	-0.305	0.040	0.184	0.651
Mining and Quarrying	0.133	-0.554	-0.117	-0.097	0.604
Food , Beverages and Tobacco	0.043	0.412	-0.107	-0.064	0.737
Textiles, Leather and Footwear	0.063	-0.144	-0.076	-0.049	0.660
Wood and Cork	0.289	-0.887	-0.059	-0.070	0.711
Pulp, Paper, Printing and Publishing	-0.100	0.257	-0.011	-0.034	0.642
Coke, Refined Petroleum and Nuclear Fuel	0.037	0.641	-0.038	-0.099	0.439
Chemicals and Chemical Products	0.151	-0.277	-0.021	-0.043	0.667
Rubber and Plastics	-0.160	-0.503	-0.023	-0.018	0.686
Other Non-Metallic Mineral	0.105	-0.595	-0.072	-0.046	0.774
Basic Metals and Fabricated Metal	-0.147	0.229	-0.104	-0.045	0.612
Machinery, NEC	-0.192	-0.158	-0.075	0.001	0.631
Electrical and Optical Equipment	-0.132	-0.391	0.084	0.177	0.710
Transport Equipment	-0.368	-0.202	-0.064	0.090	0.761
Manufacturing NEC;	0.057	-0.296	-0.115	-0.033	0.703

Recycling					
Electricity, Gas and Water Supply	0.020	-0.872	-0.243	-0.054	0.580
Construction	-0.090	-0.199	-0.211	-0.078	0.597
Sale, Maintenance and Repair of Motor Vehicles and Motorcycles; Retail Sale of Fuel	0.024	-0.471	-0.286	-0.104	0.594
Wholesale Trade and Commission Trade	0.568	-0.398	-0.233	-0.122	0.583
Retail Trade; Repair of Household Goods	0.230	-0.667	-0.212	-0.083	0.593
Hotels and Restaurants	0.007	-0.972	-0.162	-0.092	0.640
Transport and Storage	-0.235	0.282	-0.229	-0.014	0.599
Post and Telecommunications	0.457	0.128	-0.315	0.022	0.566
Financial Intermediation	0.050	-0.178	-0.244	-0.008	0.723
Real Estate Activities	0.346	-0.061	-0.241	-0.054	0.473
Renting of M&Eq and Other Business Activities	0.311	0.157	-0.286	-0.014	0.635
Public Admin and Defense; Social Security	-0.130	-0.753	-0.208	-0.065	0.731
Education	-0.015	-0.582	-0.221	-0.055	0.624
Health and Social Work	-0.145	-0.701	-0.346	-0.044	0.669
Other Community, Social And Personal Services	0.287	-0.770	-0.295	-0.072	0.654

The figures presented in Table 5.6 allow providing extensive and accurate policy suggestions for individual industries. For example, six industries are over utilizing the ICT capital in their production process, these industries are Food , beverages and tobacco, Pulp, paper, printing and publishing, Coke, refined petroleum and nuclear fuel, Transport and storage, Post and telecommunications, and Renting of M&Eq and other business activities. Their corresponding energy use level is also over used. This indicates that the ICT capital is not able to act as a reducing factor of energy intensity in these industries.

5.6 The Own and Cross Price Elasticities

The own and cross price elasticities of input demand can be explained as the percentage change in demand for the i^{th} input in response to a change in the price of the j^{th} input. Note that a positive elasticity implies that the two inputs are substitutes, while a negative one points to a complementary relationship.

The short- and long-run price and output elasticities of factor demand for South Korean and Japanese industries are calculated and reported in Table 5.7, Table 5.8, Table 5.9, and Table 5.10. The short-run elasticities of variable inputs are defined when the quasi-fixed inputs are fixed, and the long-run elasticities are defined when the inputs have adjusted fully to their steady-state levels.

Table 5. 7

Short- and Long-Run Price and Output Elasticities by Decade (South Korea)

	Short Run Elasticities														
	1980-1989					1990-1999					2000-2009				
	L	**E**	**M**	**K**	**ICT**	**L**	**E**	**M**	**K**	**ICT**	**L**	**E**	**M**	**K**	**ICT**
P^L	-0.22	0.24	0.29	0	0	-0.03	0.03	0.77	0	0	-0.01	0.01	0.34	0	0
P^E	0.24	-0.09	0.54	0	0	0.03	-0.01	0.43	0	0	0.01	-0.02	0.49	0	0
P^M	0.29	0.54	-0.03	0	0	0.78	0.43	-0.94	0	0	0.34	0.49	-0.13	0	0
P^K	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
P^{ICT}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
T	0.08	-0.23	0.64	0	0	-0.30	0.05	0.74	0	0	0.16	0.01	0.32	0	0
Y	0.02	0.55	0.20	0	0	1.09	0.20	0.10	0	0	1.01	0.90	0.10	0	0
	Long Run Elasticities														
P^L	-0.26	0.21	0.29	0.22	0.18	-0.08	-0.04	1.00	0.27	0.35	-0.02	-0.01	0.70	-0.01	0.08
P^E	0.21	-0.11	0.20	0.18	0.30	-0.04	-0.08	0.65	0.37	0.40	-0.01	-0.01	0.95	0.11	0.44
P^M	0.29	0.20	-0.03	-0.08	0.16	1.00	0.65	-1.00	-0.22	-0.16	0.70	0.95	-0.00	-0.04	0.03

P^K	0.22	0.18	-0.08	-0.08	0	0.27	0.37	-0.22	-0.16	0	-0.01	0.11	-0.04	-0.12	0
P^{ICT}	0.18	0.30	-0.16	0	-0.25	0.35	0.40	-0.16	0	-0.42	0.08	0.44	0.03	0	-0.30
T	0.08	-0.22	1.28	0.04	0.23	-0.30	0.03	1.50	-0.15	-0.05	0.16	0.06	0.60	0.12	0.23
Y	0.11	0.52	0.48	1.00	1.00	1.13	0.58	0.42	1.00	1.00	1.01	0.90	0.11	1.00	1.00

Table 5. 8

Short- and Long-Run Price and Output Elasticities of Knowledge and Non-Knowledge Based Industries (South Korea)

	Short Run Elasticities									
	Knowledge Based Industries					**Non-Knowledge Based Industries**				
	L	**E**	**M**	**K**	**ICT**	**L**	**E**	**M**	**K**	**ICT**
P^L	-0.01	0.001	0.73	0	0	-0.01	0.01	-0.05	0	0
P^E	0.001	-0.02	0.84	0	0	0.01	-0.00	0.39	0	0
P^M	0.73	0.84	-0.96	0	0	-0.05	0.39	-0.01	0	0
P^K	0	0	0	0	0	0	0	0	0	0
P^{ICT}	0	0	0	0	0	0	0	0	0	0
T	-0.23	-0.34	1.07	0	0	0.55	0.10	-0.15	0	0
Y	0.57	0.81	0.12	0	0	0.58	0.59	0.26	0	0
	Long Run Elasticities									
P^L	-0.03	-0.04	1.5	0.08	0.20	-0.03	-0.02	-0.06	0.04	0.27
P^E	-0.04	-0.12	-0.01	0.10	0.42	-0.02	-0.03	0.81	0.05	0.38
P^M	1.5	-0.01	-0.96	0.01	-0.07	-0.06	0.81	-0.49	-0.16	-0.05

P^K	0.08	0.10	0.01	-0.04	0	0.04	0.05	-0.16	-0.10	0
P^{ICT}	0.20	0.42	-0.07	0	-0.31	0.27	0.38	-0.05	0	-0.18
T	-0.23	-0.44	1.13	-0.37	-0.41	0.55	0.12	-0.31	0.20	0.44
Y	0.60	0.93	0.54	1.00	1.00	0.68	0.60	0.41	1.00	1.00

Table 5. 9

Short- and Long-Run Price and Output Elasticities by Decade (Japan)

	1974-1984					1985-1995					1996-2006				
	L	**E**	**M**	**K**	**ICT**	**L**	**E**	**M**	**K**	**ICT**	**L**	**E**	**M**	**K**	**ICT**
Short Run Elasticities															
P^L	-0.17	-0.06	0.40	0	0	-0.01	-0.01	0.41	0	0	-0.14	-0.11	0.65	0	0
P^E	-0.06	-0.11	0.47	0	0	-0.01	-0.001	0.64	0	0	-0.11	-0.05	0.69	0	0
P^M	0.40	0.47	-0.46	0	0	0.41	0.64	-0.99	0	0	0.65	0.69	-1.00	0	0
P^K	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
P^{ICT}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
T	0.06	0.14	0.17	0	0	0.11	-0.13	0.53	0	0	0.02	-0.06	0.54	0	0
Y	0.91	0.86	0.09	0	0	1.00	0.98	0.001	0	0	1.00	0.96	0.001	0	0
Long Run Elasticities															
P^L	-0.37	-0.06	0.81	0.90	0.36	-0.46	-0.06	0.99	0.73	1.00	-1.41	-0.03	1.00	0.97	1.00
P^E	-0.06	-0.12	0.50	0.26	-0.19	-0.06	-0.01	1.00	0.18	0.16	-0.03	-0.06	1.00	0.39	-0.65
P^M	0.81	0.50	-0.80	-0.90	0.30	0.99	1.00	-0.99	-0.69	-0.99	1.00	1.00	-1.00	-0.98	0.30

O^K	0.90	0.26	-0.90	-0.95	0	0.73	0.18	-0.69	-0.88	0	0.97	0.39	-0.98	-0.99	0
P^{ICT}	0.36	-0.19	0.30	0	-0.88	1.00	0.16	-0.99	0	-0.83	1.00	-0.65	0.30	0	-0.68
T	0.06	0.14	0.24	-0.02	-0.24	0.10	-0.11	1.00	0.12	0.09	0.01	-0.03	1.00	0.18	0.14
Y	0.91	0.85	0.15	1.00	1.00	1.00	1.00	0.02	1.00	1.00	1.00	0.97	0.04	1.00	1.00

Table 5. 10

Short- and Long-Run Price and Output Elasticities of Knowledge and Non-Knowledge Based Industries (Japan)

	Short Run Elasticities									
	Knowledge Based Industries					**Non-Knowledge Based Industries**				
	L	**E**	**M**	**K**	**ICT**	**L**	**E**	**M**	**K**	**ICT**
P^L	-0.03	-0.14	0.40	0	0	-0.15	0.05	0.14	0	0
P^E	-0.14	-0.03	1.27	0	0	0.05	-0.09	0.70	0	0
P^M	0.40	1.27	-1.00	0	0	0.14	0.70	-0.89	0	0
P^K	0	0	0	0	0	0	0	0	0	0
P^{ICT}	0	0	0	0	0	0	0	0	0	0
T	0.20	-0.61	0.84	0	0	0.33	-0.20	0.33	0	0
Y	0.96	0.83	0.03	0	0	0.95	0.87	0.03	0	0
	Long Run Elasticities									
P^L	-1.60	0.25	0.95	0.90	0.93	-0.83	0.09	0.54	0.71	0.94
P^E	0.25	-0.16	1.00	0.36	-0.98	0.09	-0.10	0.99	0.27	-0.30
P^M	0.95	1.00	-1.00	-0.93	0.98	0.54	0.99	-0.91	-0.75	-0.40
P^K	0.90	0.36	-0.93	-0.91	0	0.71	0.27	-0.75	-0.88	0
P^{ICT}	0.93	-0.98	0.98	0	-0.69	0.94	-0.30	-0.40	0	-0.62
T	0.21	-0.63	1.00	-0.37	-0.24	0.32	-0.21	0.64	-0.11	0.28
Y	0.97	0.85	0.17	1.00	1.00	0.96	0.88	0.13	1.00	1.00

The output elasticity of factor demand measures the percentage change in output induced by a percentage change in inputs (Siddayao et al., 1987). If the total output elasticity of factor demand is equal to one, greater than one, and less than one, a production function is said to exhibit constant, increasing, and decreasing returns to scale, respectively. All short- and long-run own-price elasticities have a negative sign as expected.

Because ICT and non-ICT capital are treated as quasi-fixed factors, their elasticities are equal to zero, and no adjustment occurs in the short-run. In the long-run, the own-price elasticities of ICT and non-ICT capital demand is less than one, which means their demand is inelastic. The demand behavior and the potential policy variables can be explained through their short- and long-run elasticities. In the short-run, the behavioral specifications and policy variables such as imposed taxes must consider that demand responses can only take the form of savings that eventually change to capital. In the long-run, however, the characteristics and the degree of availability of new technologies as well as substitutability or complementarity become applicable as the size and technological characteristics of the capital stock become variable (Hartman, 1979).

For both countries, ICT capital and labor are substitutes in all periods. In Japan, they are perfect substitutes in the last two periods. ICT diffusion caused a decrease in the labor demand in all periods, indicating the existence of ICT and labor substitution effects. These results support G. Park and Park (2003) argument that South Korean industries have increasingly used ICT machinery to reduce the use of labor, leading to the emergence of a skill-biased technological change. This indicates that the use of ICT will replace low-skilled labor but may create high-skilled, more complex jobs.

An empirical analysis on the impact of ICT investment on employment is conducted by Hong, Hong, and Lee (2010) with a sample of 498 Korean domestic sales businesses for the period 2003-2008. By estimating labor demand function and flexible cost function, the authors found that ICT investment increases employment in most of the industries except for some of the service sectors. In the manufacturing industry, more ICT investment increased employment but decreased the flexibility in the demand for labor. Thus, ICT investment has a substitution effect on the low-skilled labor and complementary effect on the high-skilled labor. In the areas of electricity, gas and construction, employment increased with the increase in the ICT investment.

As explained by Kanamori and Motohashi (2007), the labor contribution to production and GDP growth in Japan has declined because of the decrease in the Japanese birthrate, possibly leading to negative growth rate in the long-run. As a result, the increase in the TFP rate and emphasis on ICT became the most important policy initiatives for the Japanese government. The role of ICT in economic growth has continuously increased, as promoting ICT investment and accelerating the effective use of ICT are vital for the enhancement of competitiveness among Japanese industries and long-run macroeconomic growth. This trend also supports the finding that the elasticity of labor with respect to the ICT capital in the traditional industries is the same as in the knowledge-based industries. The trend of replacing labor with ICT does not differ by industry characteristics. The elasticity of labor with respect to ICT capital in the traditional industries in South Korea is higher than that in the knowledge-based industries. Industries with a high scale of R&D have more high-skilled labor, while the traditional industries that aggressively adopt ICT tend to reduce the demand for low-skilled labor (G. Park & Park, 2003).

In South Korea, ICT capital substitutes for energy use (positively in relation to time) and labor (negatively in relation to time). In Japan, however, ICT capital substitutes for energy use only during 1985–1995. During the previous and later periods, ICT complemented energy and labor (negatively in relation to time), implying that labor provides an opportunity to substitute for energy but employment is not an important factor in energy use.

The positive output elasticity of energy, which is less than 1.0 in both countries, suggests that the economic growth leads to higher energy use, but with higher energy-use efficiency. Although economic growth can improve productivity per unit of energy use, it increases total energy use and CO_2 emissions. Over time, no systematic pattern is observed in the development of energy price elasticity. This indicates that the relationship between the economic growth and the energy demand becomes more feasible after industrialization (Kamerschen & Porter, 2004). The rapid development of production capacity in South Korean industries over time has led to expansion in these industries, an urbanization process, and the economic growth (W. N. Lee et al., 2012). As a result, a change in energy price has little effect on the total demand for energy over time. The process of industrialization in South Korea has transformed its agriculture-dominated economy to a service-based one with an annual GDP growth of 2.9% (W. G. Cho et al., 2004). High growth rates of 4–5% have been observed during the four decades of industrialization. Hence, the increase in GDP per capita leads to significant increase in energy demand. The shift of industries from labor-intensive to more capital- and energy-intensive production might explain this. In addition, the urbanization process that resulted from industrialization led to more energy demand because of expansion in services, food delivery, and infrastructure development and maintenance (Liu, 2009).

The elasticity of materials accounts for the largest scale of elasticity in both South Korea and Japan. A possible explanation is that the technological progress leads to greater materials efficiency in production due to recycling wastes and reusing the materials in the production process. Another possible explanation might be that technologically advanced industries are able to change their manufacturing process over time by decreasing the use of expensive materials and redistributing resources. Moreover, the tariff exemption policy for imports of raw materials and investment goods, implemented by the South Korean government after the 1970s as part of its economic development plan, and import liberalization in general have increased the supply of low-cost material to industry (W. N. Lee et al., 2012).

5.7 Conclusion

This chapter could quantitatively assess the impact of ICT investment in South Korea and Japan on their macroeconomics in general, and on industrial energy demand in particular, using a dynamic factor demand model. Increasing ICT capital investments can improve the global competitiveness as well as productivity of South Korean and Japanese industries.

The substitution effect of ICT capital is manifested in energy-related activities, for example, by a shift from energy-intensive industries such as iron and steel and chemicals to electronic and high-tech activities with opportunities to lower energy intensity. According to the calculated elasticities, ICT capital substitutes for the energy input. However, the magnitude of the ICT capital substitution effect will determine whether or not the ICT capital decreases energy demand.

The results obtained from this chapter provide indications of the disequilibrium in the factor inputs from a long-run point of view. In addition to that, there are discrepancies between optimal and observed values of both ICT and energy inputs. Also the present of non-adjustment speed indicates that the quasi-fixed input ICT-capital is not adjustable immediately like the variable inputs.

Hence, it is necessary to further extend the study to measure and analyze the productivity growth. Moreover, under the simplifying assumptions of constant returns to scale and perfect competition (as it is the case of this model), it is relatively easy to calculate estimates of technological change using econometric and index-number techniques. However, relaxing the simplifying assumptions may help to explain the observed pro-cyclical nature of productivity growth (Diewert & Fox, 2008).

Future studies might decompose the aggregated figures of the energy input into different types of energy, to be able to evaluate their effect on industrial production and specify the substitution effects more accurately, and consider the direct ICT effects on energy conservation more effectively. The model assumed constant returns to scale. Future studies need to relax this assumption and investigate the dynamic nature of the factor demand under non-constant returns to scale.

The approach used in this study is rooted in individual industry optimization estimated from aggregated industry data. The criterion of internal closure of the model indicates that industries are taken as entities without history. The energy demand for all firms within the same industry is viewed as the same because they are assumed to have identical demand curves and face similar cost curves. Industries are commonly studied from the point of view of a representative firm. The cost function used in this study is the assumed cost function of a representative industry. These can explicitly explain the major limitation of this study.

In summary, the application of a dynamic factor demand model with ICT and non-ICT as quasi-fixed inputs produces interesting results. The model lends itself to modifications for future research. A future study employing flexible functional form under rational expectations may provide more insight into the ICT capital effect on energy demand. Incorporating some important intangible factors into the model, relaxing the constant returns to scale assumption, and relaxing the separability between the quasi-fixed factors to allow for interaction between them could show the effects of the intangible factors.

Chapter 6: Productivity Analysis of the South Korean Industrial Sectors

This chapter presents empirical findings on industrial productivity changes in South Korea between 1980 and 2009, focusing on how investment in ICT and energy use, influence the productivity growth. A dynamic factor demand model is applied which allows for considerable flexibility in the choice of the functional form of the production technology, and in the expectation formation process. The objective is to estimate the production structure, and the demand for energy, materials, labors, ICT capital, and non-ICT capital for 30 South Korean industrial sectors. In particular the focus is on the ICT capital-energy use relationship, and the effect of this relationship on the TFP growth.

This chapter provides estimates for short- and long-run input price and output elasticities, estimates of the output growth and the capacity utilizations, and also discusses the issue of measuring technological change if the industry is in the temporary equilibrium rather than in the long-run equilibrium. The assumption of linear homogenous of the production technology is relaxed and apply homothetic production function. Finally, the chapter provides estimates of input and output based technological change, and estimates for the returns to scale, and then decomposes the traditional measure of TFP. Describing industry-specific productivity levels is important for policymakers when the allocation of public investment and support is limited. The results of this study are expected to give useful information to policy makers who attempt to promote the productivity in the industries.

6.1 Introduction

Since Schumpeter (1939) emphasized that entrepreneurship is the main engine of the economic growth, many researchers have attempted to explain the causal relationship between such a growth and the technological development. Solow (1957) introduced the residual approach to measure the contribution of the technological development to the productivity growth. He found that approximately 70% of productivity increase is attributed to technological change.

Technology is considered to be the main driver engine of the economic growth. Indeed, researchers suggest that ideas and innovations are acting as a *deus ex machine* and serve to grow the TFP (Mokyr, 2005), which in turn raises the world income per capita, transforms the production processes, and modifies the way business runs (Maddison, 2005). Historical examples of the link between new technologies with growth abound. Since the 18th century when general purpose technologies such as steam engines, electricity, automobiles, and telephones were introduced during the Industrial Revolution, the living standards have dramatically increased. Similarly, in the late 1990s for some countries, for example, the US, the investment in new ICT capital implied a radical change in the underlying structure of the economy. After an extended and unexpected stagnation during the 1970s and 1980s, the US has experienced high levels of output growth associated with a strong and widespread productivity boom owing to ICT improvements (van Ark, Inklaar, & McGuckin, 2003).

South Korea is a new industrialized economy that has also taken advantage of the technological development, thereby serving as an economic model for emerging economies. It enjoyed a high economic growth rate from the post-war period until 1997, at which its per capita GDP was 10,000 USD. The South Korean economy quickly recovered from the Asian Financial Crisis of the late 1990s, the ICT bubble of 2001, and the credit crunch of 2003 (Borensztein & Lee, 2000; D. Oh et al., 2012). Moreover, it was the first country to recover within a year from the Global Economic Crisis of 2007/08. In addition, through the conclusion of negotiations on a U.S–South Korea free trade agreement (FTA), and a potential Japan–South Korea FTA in the future, the liberalization of South Korean markets will continue (Fukao, Miyagawa, & Pyo, 2009).

The high growth rate of the South Korean economy has been continued over the past four decades until the year 1997, when per capita GDP was 10,000 USD. However, its economy encountered a Monetary Crisis in November 1997. As a result the GDP has decreased by 6.7% in 1998 and around 40% of contraction in the fixed investment. Moreover the average monthly bankruptcies of all firms were more than 3,000 in the year 1998. In spite of these difficulties, the South Korean economy recovered after a short period and the crises ended in 2001. The ICT bubble of 2001 and the Credit Crunch Crisis in 2003 also affected the South Korean economy in which it was a result of the poor capital structure of enterprises (Borensztein & Lee, 2000; D. Oh et al., 2012).

This chapter presents empirical findings on industrial productivity changes in South Korea between 1980 and 2009. The contribution of this chapter in terms of empirics is to provide an independent assessment of South Korea’s growth experience. The main objectives are as follows:

The first objective is to examine the structure of factors affecting productivity in these industries. In particular the focus is on the ICT capital-energy use relationship, and the effects of this relationship on the TFP growth. The results are expected to reveal the state of productivity in each individual industry, which are important basic knowledge for policy makers in designing industrial policy and the allocation of public investment and supports. Thus the results of this study are expected to give useful information to policy makers who attempt to promote the productivity in the industries and the national level.

The second objective is to discuss empirical and theoretical issues related to identifying and estimating the sources of the industries' productivity growth, technical change, and efficiency in terms of two approaches: The index number analysis and econometric approach. The former is non-parametric and designed to calculate the first order approximation of TFP, while the later approach is parametric and a flexible technique, which is not only identifying the sources of productivity growth, but also for considering the estimation of TFP growth, its underlying components, and technical efficiency of industries by explicitly specifying the underlying cost structure.

The index number analysis approach by its construction cannot distinguish between a production function shift (which means technical progress) and movements along a production function (which means changes in technical efficiency). Hence, the third objective is to examine the industries' productivity considering both the index number analysis and econometric approach, and to compare the results for matters of sensitivity analysis. As such the two approaches are complementary and strengthen reliability and interpretation of the results. So far studies using these two methods of dynamic factor demand and Divisia approaches have been conducted separately and relatively little attention have been paid to examine the commonalities and differences between the two sets of results and factors explaining the differences.

Rest of this chapter is organized as follows. In section 2 the tradition measure of TFP via Divisa index and its limitations are explained. Section 3 presents the theoretical model under the assumption of infinite planning horizon with non-static expectation and derives the factor demand equations for the empirical analysis. In section 4 the decomposition of the traditional measure of TFP growth is provided based on components attributed to technical changes, scale, equilibrium effects, and the adjustment costs effects. Section 5 presents the result of calculating the difference between optimal input path and observed inputs. The results of parameter estimates, price and output elasticity in short- and long-run, measures of capacity utilization, as well as decomposition results of the TFP, and the growth of output are presented in sections 6–10. Section 11 concludes the chapter.

6.2 Divisia Index

Productivity is a concept used to measure the effectiveness of capital, labor, and other inputs in the process of producing goods and services (output). Investment in both physical and human capital allows more output to be produced with a given level of inputs. Changes in productivity can therefore be calculated by comparing the growth of output with the growth of inputs. To the extent that over a particular time interval, output grows faster than inputs, there is evidence that productivity has increased (Tangen, 2002).

This is the basis of the widely used Divisia index approach to calculate the TFP. On the input side it is clear that firms and industries use different inputs such as labor, physical capital, ICT capital, energy, and materials. The overall growth of inputs is therefore a weighted average of the growth rates of the individual inputs.

In the absence of input and output elasticities, the Divisia index method weights inputs and output based on cost and revenue proportions. For example, if twice as much is spent by a firm on labor as on capital, the input index weights the labor input twice as heavily as the capital input. Thus as the cost proportions are changed over time, so too the weights used in the Divisia index. Similarly, firms and industries typically produce a range of different outputs. The growth of overall output can be computed as a weighted average of the growth of individual outputs.

The Divisia index method uses the relative dollar values of output (revenue shares) as the weights. The growth of TFP over a specific time interval such as a year is calculated by subtracting the growth of the input index from the growth of the output index. The KLEMS growth and productivity database contains the information required to calculate the growth of TFP using the Divisia index method and the results of these calculations are presented in this chapter.

The accuracy of the Divisia index method rests on a number of assumptions that may not hold precisely in practice. For example, if a production process benefits from economies of scale, a one percent increase in all inputs will result in an increase in output by something in excess of one percent. In this case, the Divisia index approach to calculate productivity growth will attribute the scale effect to an improvement in TFP, since all of the differences between output growth and input growth are attributed to changes in TFP or technical change (Nadiri & Prucha, 1990). In fact, the Divisia index approach implicitly assumes the production process to exhibit constant returns to scale. That is a one percent increase in all inputs will generate a one percent increase in output. An improved method would be not to make such a restrictive assumption, and to be able to distinguish a scale effect from enhanced TFP.

Similarly, over the business cycle there are likely to be variations in the utilization rates of inputs such as capital and labor (Schumpeter, 1939). During an economic downturn, a firm or an industry face excess capacity particularly with respect to physical capital. The firm may also prefer to retain labor, that is expensive to train rather than risk losing employees that will likely be needed when demand peaks up (Belorgey, Lecat, & Maury, 2006). Labor hoarding is a common practice among firms due to high costs of hiring and firing labor. The Divisia index method does not take into account such variations in input utilization rates, and is consequently subjected to another potential source of bias than non-constant returns to scale in the estimates of TFP growth. For example, during the recovery phase following a recession, increases in output may be supported by higher utilization rates of capital and labor through over time, and shift works, and there might not be any measurable increase in inputs (no new investment in physical capital and no new hiring of personnel). In this situation, the increase in output would be attributed to an increase in TFP by the Divisia index approach rather than to higher rates of factors utilization.

A parametric flexible framework is developed to compute the TFP that relaxes many of the restrictive assumptions inherent in the Divisia index methodology (Nadiri & Prucha, 1986, 1990, 1996, 1999, 2001). Accordingly, this study applies Nadiri and Prucha (1990) model to provide a rich set of observations on the industrial sectors for South Korea. The analysis is based on a dynamic factor demand model which links inter-temporal production decisions by explicitly recognizing that the level of certain factors of production cannot be changed without incurring some costs so called "adjustment costs", and are defined in terms of forgone output from current production.

It is worthy of mentioning that not all inputs are subjected to adjustment costs. Some inputs such as labor and materials (or so called intermediate inputs) that can be adjusted very easily are called variable factors, while others, like ICT capital and non-ICT capital are subjected to adjustment cost. They are only adjusting partially in the first period, these are referred to as quasi-fixed inputs, meaning they are fixed in the short-run but tend to become variable in the long-run. Since the output growth has been fairly high in the industrial sectors in South Korea, a priori constant returns to scale is not imposed. Rather, returns to scale is estimated empirically from the data. Since the rate of ICT capital in the industrial sectors is considerably high, the ICT capital is explicitly incorporated as one of the inputs.

The stocks of ICT capital and non-ICT capital are considered both to be quasi-fixed inputs, while labor (hours worked), energy and materials are considered to be variable factors in the production process. Materials is usually proportional to the output quantity produced. By using the structural parameter estimates, this study analyzes the sources of growth in output, and

TFP and its growth rate.

The statistical estimation results in a rich set of information on the production process. In particular, the sensitivities of input demands to factor prices are measured through both short- and long-run price elasticities, for example, how much does the demand for labor change in response to when industry wages rise. When energy prices rise, firms will economize on energy use. The reaction to a potentially permanent increase in energy prices is likely to be less in the immediate future than it will be after a period of time and adjustments.

Hence the distinction can be observed between short- and long-run price elasticities attribute to fix and variable nature of inputs. Features of the industry‘s technology are captured by such measures of a scale economies and the degree of substitutability between the various inputs. Economies of scale indicate whether an expansion of output can be achieved through constant, rising or falling average unit costs. The substitutability of inputs reveals to what extent capital investment can, for example, reduce energy use or hours of labor per unit of output. Finally, the estimated model is capable of decomposing the Divisia Index measure of TFP into a rigorously defined measure of TFP and, the biases that result from the presence of scale economies and variations in factor utilization rates.

6.3 Theoretical Model and Empirical Specification

The dynamic factor demand model is again applied in this chapter. However the specification is differ from the previous chapter in two aspects: First, A sensitivity analysis is conducted and accordingly instead of time trend interactions with the variable inputs as used in the previous chapter, here a simple time trend is used to represent the industries' technology. Second the returns to scale is estimated endogenously from the model, hence the assumption of constant returns to scale is released and thus provides better insight for the effects of scale on the productivity.

Accordingly, to explain the theoretical specification of the dynamic factor demand model, the departure will be from the minimization problem described in equation (7) from the previous chapter. The normalized restricted cost function *G(.)* in a quadratic form, as introduced by Denny et al. (1981), can be described as follows:

(8-1) $$G\left(p_{i,t}^{L}, p_{i,t}^{E}, K_{i,t-1}, ICT_{i,t-1}, \Delta K_{i,t}, \Delta ICT_{i,t}, h(Y_{i,t}), T_{i,t}\right) = \Big[a_0 + a_T T_{i,t} + a_l p_{i,t}^{L} + a_e p_{i,t}^{E} + a_{el} p_{i,t}^{L} p_{i,t}^{E} + \frac{1}{2} a_{ll}\left(p_{i,t}^{L}\right)^2 + \frac{1}{2} a_{ee}\left(p_{i,t}^{E}\right)^2\Big] h(Y_{i,t}) + a_K K_{i,t-1} + a_{ICT} ICT_{i,t-1} + a_{lK} p_{i,t}^{L} K_{i,t-1} + a_{lICT} p_{i,t}^{L} ICT_{i,t-1} + a_{eK} p_{i,t}^{E} K_{i,t-1} + a_{eICT} p_{i,t}^{E} ICT_{i,t-1} + \left[\frac{1}{2} a_{KK} \mathrm{K}_{i,t-1}^2 + \frac{1}{2} a_{ICTICT} \mathrm{ICT}_{i,t-1}^2 + \frac{1}{2} a_{\dot{K}\dot{K}} \Delta \mathrm{K}_{i,t}^2 + \frac{1}{2} a_{I\dot{C}TI\dot{C}T} \Delta \mathrm{ICT}_{i,t}^2\right] \frac{1}{h(Y_{i,t})}$$

where p^E, p^L, p^{ICT}, and p^K are prices for *E*, *L*, *ICT*, and *K* normalized by the price of *M*, respectively. $h(Y) = Y^{\Omega_0 + \Omega_1 \ln(Y)}$ is an output scale function.

The normalized restricted cost function specified in equation (8-1) corresponding to a homothetic production function. Its general form is described as follows:

(9-1) $$\mathrm{g}\left(p_{i,t}^{L}, p_{i,t}^{E}, \frac{K_{i,t-1}}{H(Y)}, \frac{ICT_{i,t-1}}{H(Y)}, \frac{\Delta K_{i,t-1}}{H(Y)}, \frac{\Delta ICT_{i,t-1}}{H(Y)}, T\right) H(Y)$$

where *H(Y)* is a function in Y. The elasticity scale can then be obtained as $H(Y)/Y\ (dY/dH)$. For a homothetic production function, the scale elasticity is a function of output alone, it is independent of any specific direction of change in inputs (Hanoch, 1975). A value of the scale elasticity equal to one, less than one, and greater than one indicates constant, decreasing, and increasing returns to scale, respectively (Stefanou, 1989).

The returns to scale can be measured as an inverse of scale elasticity (Nadiri & Prucha, 1999). The marginal adjustment cost needs to be equal to zero in the steady state of quasi-fixed inputs when ΔK and ΔICT are equal to zero. Hence, $\partial G(.)/\partial \Delta K$ and $\partial G(.)/\partial \Delta ICT$ will be zero at $\Delta K = \Delta ICT = 0$ only if the following restrictions are imposed on the estimated parameters (Denny et al., 1981):

(10-1) $a_{\dot{K}} = a_{I\dot{C}T} = a_{l\dot{K}} = a_{lI\dot{C}T} = a_{K\dot{K}} = a_{ICTI\dot{C}T} = a_{\dot{K}I\dot{C}T} = a_{ICT\dot{K}} = a_{T\dot{K}} = a_{TI\dot{C}T} = 0$

where a dot over a variable represents the growth rate in the quasi-fixed inputs. Imposing the separability assumption, as recommend by Nadiri and Prucha (1990), on the quasi-fixed inputs will simplify the derivation of the dynamic factor demand model. In this study, separability of the quasi-fixed input implies that $a_{KICT} = a_{\dot{K}I\dot{C}T}$.

The convexity and concavity conditions of the normalized restricted cost function under the separability assumption imply that $a_{KK}, a_{ICTICT}, a_{\dot{K}\dot{K}}, a_{I\dot{C}TI\dot{C}T} > 0$ and $a_{ll}, a_{ee} < 0$. The optimal input paths of investment in ICT and non-ICT capital must satisfy the necessary conditions given by the Euler equations (Toro, 2009), obtained by solving equation (7) with respect to *K* and *ICT* as follows:

(11-1) $-a_{\dot{K}\dot{K}}K_{i,t+\tau+1} + [a_{\dot{K}\dot{K}} + (2+r_t)a_{\dot{K}\dot{K}}]K_{i,t+\tau} - (1+r_t)a_{\dot{K}\dot{K}}K_{i,t+\tau-1}$

$$= -\left((1-\delta)p_{i,t}^{K} + a_K + a_{lK}p_{i,t}^{L} + a_{eK}p_{i,t}^{E} + a_{TK}T_{i,t}\right)Y_{i,t}$$

(12-1) $-a_{I\dot{C}TI\dot{C}T}ICT_{i,t+\tau+1} + [a_{I\dot{C}TI\dot{C}T} + (2+r_t)a_{I\dot{C}TI\dot{C}T}]\mathrm{ICT}_{i,t+\tau} -$ $(1+r_t)a_{I\dot{C}TI\dot{C}T}\mathrm{ICT}_{i,t+\tau-1}$

$$= -\left((1-\mu)p_{i,t}^{ICT} + a_{ICT} + a_{lICT}p_{i,t}^{L} + a_{eICT}p_{i,t}^{E} + a_{TICT}T_{i,t}\right)Y_{i,t}$$

The transversality conditions below will rule out the unstable roots for the Euler equations:

$\lim_{n\to\infty}(1+r_\tau)^{\tau}\left(a_{\dot{K}\dot{K}}K_{i,t+\tau} - a_{\dot{K}\dot{K}}K_{i,t+\tau-1}\right) = 0$, and

$\lim_{n\to\infty}(1+r_\tau)^{\tau}\left(a_{I\dot{C}TI\dot{C}T}\mathrm{ICT}_{i,t+\tau} - a_{I\dot{C}TI\dot{C}T}\mathrm{ICT}_{i,t+\tau-1}\right) = 0$.

The accelerator equations as described by Nadiri and Prucha (1990) serve as a solution corresponding to the stable roots for the Euler equations as follows:

(13.1-1) $\Delta K_{i,t} = m_{KK}\left(K_{i,t}^{*} - K_{i,t-1}\right)$

(13.2-1) $\Delta ICT_{i,t} = m_{ICTICT}\left(ICT_{i,t}^{*} - ICT_{i,t-1}\right)$

(13.3-1) $m_{KK} = -\frac{1}{2}\left[(r_t + a_{KK}/a_{\dot{K}\dot{K}}) - ((r_t + a_{KK}/a_{\dot{K}\dot{K}})^2 +\right.$ $\left.4\,a_{KK}/a_{\dot{K}\dot{K}})^{1/2}\right]$

(13.4-1) $m_{ICTICT} = -\frac{1}{2}\left[(r_t + a_{ICTICT}/a_{I\dot{C}T I\dot{C}T}) - ((r_t + a_{ICTICT}/a_{I\dot{C}T I\dot{C}T})^2 + 4\, a_{ICTICT}/a_{I\dot{C}T I\dot{C}T})^{1/2}\right]$

(13.5-1) $K^*_{i,t} = -\frac{1}{a_{KK}}\left[(r_t + \delta)p^K_{i,t} + a_K + a_{lK}p^L_{i,t} + a_{eK}p^E_{i,t}\right]h(Y_{i,t})$

(13.6-1) $ICT^*_{i,t} = -\frac{1}{a_{ICTICT}}\left[(r_t + \mu)p^{ICT}_{i,t} + a_{ICT} + a_{lICT}p^L_{i,t} + a_{eICT}p^E_{i,t}\right]h(Y_{i,t})$

where a star indicate optimal or target levels of the quasi-fixed inputs. Substituting the steady solutions of the Euler equations (11-1) and (12-1), and the adjustment coefficient forms (13.3-1) and (13.4-1) into the accelerator coefficients (13.1-1) and (13.2-1), respectively, in line with Nadiri and Prucha (1990) gives the optimal quasi fixed input path for *ICT* and *K* as follows:

(14-1) $\Delta K_{i,t} = (-\frac{1}{2}\left[(r_t + a_{KK}/a_{\dot{K}\dot{K}}) - ((r_t + a_{KK}/a_{\dot{K}\dot{K}})^2 + 4\, a_{KK}/a_{\dot{K}\dot{K}})^{1/2}\right]) * \left(-\frac{1}{a_{KK}}\left[(r_t + \delta)p^K_{i,t} + a_K + a_{lK}p^L_{i,t} + a_{eK}p^E_{i,t}\right]h(Y_{i,t}) - K_{i,t-1}\right)$

(15-1) $\Delta ICT_{i,t} = (-\frac{1}{2}\left[(r_t + a_{ICTICT}/a_{I\dot{C}T I\dot{C}T}) - ((r_t + a_{ICTICT}/a_{I\dot{C}T I\dot{C}T})^2 + 4\, a_{ICTICT}/a_{I\dot{C}T I\dot{C}T})^{1/2}\right]) * \left(-\frac{1}{a_{ICTICT}}\left[(r_t + \mu)p^{ICT}_{i,t} + a_{ICT} + a_{lICT}p^L_{i,t} + a_{eICT}p^E_{i,t}\right]h(Y_{i,t}) - ICT_{i,t-1}\right)$

By Shephard's lemma (Shephard, 1953), the variable input demand equations for *L*, *E*, and *M* can be obtained as follows:

(16-1) $L_{i,t} = \frac{\partial G(.)}{\partial p^L_{i,t}} = \left(a_l + a_{ll}p^L_{i,t} + a_{el}p^E_{i,t}\right)h(Y_{i,t}) + a_{lK}K_{i,t-1} + a_{lICT}ICT_{i,t-1}$

(17-1) $E_{i,t} = \frac{\partial G(.)}{\partial p_{i,t}^E} = \left(a_e + a_{ee}p_{i,t}^E + a_{el}p_{i,t}^L\right)h(Y_{i,t}) + a_{eK}K_{i,t-1} +$

$a_{eICT}ICT_{i,t-1}$

From $G(.) = M_{i,t} + p_{i,t}^L L_{i,t} + p_{i,t}^E E_{i,t}$, the demand equation for *M* is described as follows:

(18-1) $M_{i,t} = G(.) - p_{i,t}^L L_{i,t} - p_{i,t}^E E_{i,t} = \Big[a_0 + a_T T_{i,t} - \frac{1}{2}a_{ll}\left(p_{i,t}^L\right)^2 -$

$\frac{1}{2}a_{ee}\left(p_{i,t}^E\right)^2 - a_{el}p_{i,t}^L p_{i,t}^E\Big]h(Y_{i,t}) + a_K K_{i,t-1} + a_{ICT}ICT_{i,t-1} + \Big[\frac{1}{2}a_{KK}\mathrm{K}_{i,t-1}^2 +$

$\frac{1}{2}a_{ICTICT}\mathrm{ICT}_{i,t-1}^2 + \frac{1}{2}a_{\dot{K}\dot{K}}\Delta\mathrm{K}_{i,t}^2 + \frac{1}{2}a_{IC\dot{T}IC\dot{T}}\Delta\mathrm{ICT}_{i,t}^2\Big]\frac{1}{h(Y_{i,t})}$

The entire system of equations to be estimated consists of the two quasi-fixed inputs (*K* and *ICT*) and three variable inputs (*L*, *E*, and *M*) presented in equations (14-1) to (18-1). A stochastic error term is added to each equation to capture the random errors in the cost minimization problem. Dummy variables for individual Industry are also added to capture the industries' fixed effects due to presence of panel data. The system of equations is non-linear in both parameters and variables, and hence need to be estimated with non-linear estimation methods. When necessary, the first order autocorrelation is corrected for the disturbances as recommended by Nadiri and Prucha (2001). The model parameters were estimated by the Full Information Maximum Likelihood (FIML) method with the SAS 9.3 application package.

The Durbin-Watson test developed by Durbin and Watson (1950) is a widely used method of testing for autocorrelation. This statistic can be used to test for the first-order autocorrelation. According to the Durbin Watson test results there is a serial correlation of order 1, and need to be corrected.

However, a different approach to the simultaneous equation bias problem is the FIML estimation method. FIML does not require instrumental variables, but it assumes that the equation errors have a multivariate normal distribution (SAS Institute Inc, 1993).

Since the estimated model is dynamic, even if all the explanatory variables are uncorrelated with the error components, the presence of serial correlation in the remainder error term, or the presence of a random industry effect renders the lagged dependent variable correlated with the error term, and leads to inconsistent least squares estimates. Even the within estimator, which eliminates the industry-specific effects, is biased unless T tends to infinity (Baltagi & Griffin, 1997; Kiviet, 1995). Hence, in applying the maximum likelihood estimation approach, one should assume that the distribution of error terms, in a system, have multivariate normal distributions (Pindyck & Rubinfeld, 2012).

6.4 Determinants of the TFP Growth

The Divisia index is defined as a weighted sum of the growth rate in outputs minus the weighted sum of growth rate of the input variables. The weights are the outputs revenues shares and input variables' shares in the total cost. Tornqvist index is a discrete approximation to a continuous Divisia index in economics averaging the measure at two adjacent time periods. It is attractive because of smoothing the changes and better capturing trends. If the TFP growth rate is measured by the conventional Divisia index, the corresponding Tornqvist index is defined as:

(19) $\Delta TFP_{it} = \Delta lnY_{it} - \Delta lnN_{it}$

where ΔlnY_{it} is the growth rate of the output and ΔlnN_{it} is the growth rate of cost share weighted index of aggregate inputs. The input growth rate component is defined as follows:

(20) $$\Delta lnN_{it} = \frac{1}{2}\left[\left(\frac{M_{it}}{C_{it}} + \frac{M_{it-1}}{C_{it-1}}\right)\Delta lnM_{it} + \left(\frac{p_{it}^{L}L_{it}}{C_{it}} + \frac{p_{it-1}^{L}L_{it-1}}{C_{it-1}}\right)\Delta lnL_{it} + \left(\frac{p_{it}^{E}E_{it}}{C_{it}} + \frac{p_{it-1}^{E}E_{it-1}}{C_{it-1}}\right)\Delta lnE_{it}\right] + \frac{1}{2}\left[\left(\frac{c_{it}^{K}K_{it-1}}{C_{it}} + \frac{c_{it-1}^{K}K_{it-2}}{C_{it-1}}\right)\Delta lnK_{it-1} + \left(\frac{c_{it}^{ICT}ICT_{it-1}}{C_{it}} + \frac{c_{it-1}^{ICT}ICT_{it-2}}{C_{it-1}}\right)\Delta lnICT_{it-1}\right]$$

where $C_{it} = M_{it} + p_{it}^{L}L_{it} + p_{it}^{E}E_{it} + c_{it}^{K}K_{it-1} + c_{it}^{ICT}ICT_{it-1}$ is the total cost *C*, and $c_{it}^{K} = p_{it}^{K}(r_t + \delta)$ and $c_{it}^{ICT} = p_{it}^{ICT}(r_t + \mu)$ are the long run rental price for *ICT* and *K*, respectively.

The technical change measure according to Solow residual is often measured as the difference between the growth rates of aggregated output to the growth rate of aggregated inputs. Divisia aggregation is often used to compete aggregated outputs and inputs that were developed by Jorgenson and Griliches (1967), Richter (1966), Hulten (1973), and Diewert (1976). However, as argued by Nadiri and Prucha (2001), the TFP growth based on Divisia index will generate biased estimates of technical changes, which may include scale effects and temporarily equilibrium effects. In case if any one of the sets of the assumptions that the Divisia index is biased on are violated [11]. Empirical results and unrealistic restrictiveness of the assumptions lead to preference for alternative parametric TFP growth measures. Accordingly, the

[11] The assumptions are (i) producers are in long run equilibrium, (ii) the technology exhibits constant returns to scale, (iii) output and inputs markets are competitive, and (iv) input factors are utilized at a constant rate (Nadiri & Prucha, 2001).

growth of TFP has been decomposed as follows (Nadiri & Prucha, 1986, 1990, 2001):

$$(21) \qquad \Delta TFP_{i,t} = \Delta TFP_{i,t}^{T} + \Delta TFP_{i,t}^{S} + \Delta TFP_{i,t}^{E} + \Delta TFP_{i,t}^{A}$$

The overall TFP growth rate is decomposed into the following components: Technical change, scale effect, equilibrium effect, and the direct adjustment effect. These components are described below:

Based on the Tornqvist notion, the technical change effect component is as follows:

$$(22) \qquad \Delta TFP_{i,t}^{T} = \frac{1}{2}[\lambda_x(t) + \lambda_x(t-1)]$$

where the input based measure of technical change is obtained from the following relation:

$$(23) \quad \lambda_x = -\frac{\partial G_{i,t}}{\partial T_{i,t}} \Bigg/ \left[\begin{array}{c} G_{i,t} - \left(\frac{\partial G_{i,t}}{\partial K_{i,t-1}} K_{i,t-1} + \frac{\partial G_{i,t}}{\partial ICT_{i,t-1}} ICT_{i,t-1} \right) \\ - \left(\frac{\partial G_{i,t}}{\partial \Delta K_{i,t}} \Delta K_{i,t} + \frac{\partial G_{i,t}}{\partial \Delta ICT_{i,t}} \Delta ICT_{i,t} \right) \end{array} \right]$$

The input based measure of technical change is corresponding to the decrease in input use achieved with technical change without decreasing the output (Caves, Christensen, & Diewert, 1982; Caves, Christensen, & Swanson, 1981).

The output based measure of technical change is obtained from the following relation:

$$(24) \qquad \lambda_Y = -\frac{\partial G_{it}}{\partial T_{i,t}} \Big/ \left(\frac{\partial G_{i,t}}{\partial Y_{i,t}} h(Y_{i,t}) \right)$$

The returns to sale is defined as $\varepsilon = \frac{\lambda_Y}{\lambda_x}$ and the technical change $TC = (\partial G/\partial t)/C$ (Nadiri & Prucha, 1990). The output-based measure of technical change is the rate of expansion in output achieved by technical change without changing the input use (Caves et al., 1982; Caves et al., 1981).

The scale effect or deviation from constant returns to scale is specified as follows:

(25) $\Delta TFP_{i,t}^{S} = (1 - \varepsilon_{i.t}^{-1})\Delta \ln(h(Y_{i,t}))$

The temporary equilibrium effect is specified as follows:

(26) $\Delta TFP_{i,t}^{E} = -\frac{1}{2}\sum_{\tau=t,t-1}\left\{\frac{(\partial G_{i,\tau}/\partial K_{i,\tau}+c_{i,\tau}^{K})K_{i,\tau}}{\varepsilon_{i,\tau}(\partial G_{i,\tau}/\partial Y_{i,\tau})Y_{i,\tau}}\left[\Delta lnK_{i,t} - \Delta lnN_{i,t}^{\tau}\right]\right\} - \frac{1}{2}\sum_{\tau=t,t-1}\left\{\frac{(\partial G_{i,\tau}/\partial ICT_{i,\tau}+c_{i,\tau}^{ICT})ICT_{i,\tau}}{\varepsilon_{i,\tau}(\partial G_{i,\tau}/\partial Y_{i,\tau})Y_{i,\tau}}\left[\Delta lnICT_{i,t} - \Delta lnN_{i,t}^{\tau}\right]\right\}$

While the direct adjustment cost effect is described as follows:

(27) $\Delta TFP_{i,t}^{A} = -\frac{1}{2}\sum_{\tau=t,t-1}\left\{\frac{(\partial G_{i,\tau}/\partial \Delta K_{i,\tau})\Delta K_{i,\tau}}{\varepsilon_{i,\tau}(\partial G_{i,\tau}/\partial Y_{i,\tau})Y_{i,\tau}}\left[\Delta ln\Delta K_{i,t} - \Delta lnN_{i,t}^{\tau}\right]\right\} - \frac{1}{2}\sum_{\tau=t,t-1}\left\{\frac{(\partial G_{i,\tau}/\partial \Delta ICT_{i,\tau})\Delta ICT_{i,\tau}}{\varepsilon_{i,\tau}(\partial G_{i,\tau}/\partial Y_{i,\tau})Y_{i,\tau}}\left[\Delta ln\Delta ICT_{i,t} - \Delta lnN_{i,t}^{\tau}\right]\right\}$

According to the Lemma developed by Nadiri and Prucha (1990), the relationship between the derivatives of the production function $F(V,X,\Delta X,T)$ and the restricted cost function $G(p^V,X, \Delta X,Q,T)=V_1+ p^{v2}V_2+ p^{v3}V_3$ can be expressed as follows:

$$\frac{\partial F}{\partial V_1} = \frac{1}{\partial G/\partial Y} \;, \quad \frac{\partial F}{\partial V_2} = \frac{p^{V_2}}{\partial G/\partial Y} \;, \quad \frac{\partial F}{\partial V_3} = \frac{p^{V_3}}{\partial G/\partial Y} \;,$$

$$\frac{\partial F}{\partial X_{1,t-1}} = -\frac{\partial G/\partial X_{1,t-1}}{\partial G/\partial Y} \quad , \qquad \frac{\partial F}{\partial X_{2,t-1}} = -\frac{\partial G/\partial X_{2,t-1}}{\partial G/\partial Y} \quad ,$$

$$\frac{\partial F}{\partial \Delta X_{1,t-1}} = -\frac{\partial G/\partial \Delta X_{1,t-1}}{\partial G/\partial Y} \quad , \qquad \frac{\partial F}{\partial \Delta X_{2,t-1}} = -\frac{\partial G/\partial \Delta X_{2,t-1}}{\partial G/\partial Y} \quad ,$$

$$\frac{\partial F}{\partial T} = -\frac{\partial G/\partial T}{\partial G/\partial Y}$$

Differentiating the production function *F(V,X,ΔX,T)* with respect to time, and by dividing output, one gets the decomposition of output growth outlined above:

(28) $\Delta \ln \mathrm{Y}_{i,t} = \frac{1}{2}\left[\left(\epsilon_{FL}(t) + \epsilon_{FL}(t-1)\Delta \ln \mathrm{L}_{i,t}\right) + \left(\epsilon_{FE}(t) + \epsilon_{FE}(t-1)\Delta \ln \mathrm{E}_{i,t}\right) + \left(\epsilon_{FM}(t) + \epsilon_{FM}(t-1)\Delta \ln \mathrm{M}_{i,t}\right) + \left(\epsilon_{FK_{t-1}}(t) + \epsilon_{FK_{t-1}}(t-1)\Delta \ln \mathrm{K}_{i,t-1}\right) + \left(\epsilon_{FICT_{t-1}}(t) + \epsilon_{FICT_{t-1}}(t-1)\Delta \ln \mathrm{ICT}_{i,t-1}\right) + \left(\epsilon_{F\Delta \mathrm{K}}(t) + \epsilon_{F\Delta \mathrm{K}}(t-1)\Delta \ln \Delta \mathrm{K}_{i,t}\right) + \left(\epsilon_{F\Delta ICT}(t) + \epsilon_{F\Delta \mathrm{ICT}}(t-1)\Delta \ln \Delta \mathrm{ICT}_{i,t}\right)\right] + \frac{1}{2}\left[\lambda_Y(t) + \lambda_Y(t-1)\right]$

The shadow price of X_{t-1} and ΔX and the shadow cost C^S are defined as follows:

(29) $C^S = G + \sum_{j=1}^{2} u_j X_{j,t-1} + \sum_{j=1}^{2} \dot{u}_j \Delta X_{jt}\,, where\ u_j = -\frac{\partial G}{\partial X_{j,t-1}}\ and\ \dot{u}_j = -\frac{\partial G}{\partial \Delta X_j}$

The total cost *C*, shadow cost C^s and the returns to scale ε imply that $C^S = \varepsilon(\partial G/\partial Y)Y$

From the relationship between the derivatives of the production function and the restricted cost function and decomposition of output growth, one can obtain the following relations:

(30) $\Delta \ln \mathrm{Y}_{i,t}^{\tau} =$

$$\varepsilon \begin{bmatrix} p_{i,\tau}^{L} L_{i,\tau} \Delta ln L_{i,t} + p_{i,\tau}^{E} E_{i,\tau} \Delta ln E_{i,t} + p_{i,\tau}^{M} M_{i,\tau} \Delta ln M_{i,t} + u_{Ki,\tau} K_{i,\tau-1} \Delta ln K_{i,t-1} \\ + u_{ICTi,\tau} ICT_{i,\tau} \Delta ln ICT_{i,t-1} + \dot{u}_{Ki,\tau} K_{i,\tau} \Delta ln \Delta K_{i,t} + \dot{u}_{ICTi,\tau} ICT_{i,\tau} \Delta ln \Delta \mathrm{ICT}_{i,t} \end{bmatrix} /$$

$C_{i,\tau}^{S} + +\lambda_{Y}(t)$

(31) $\Delta \ln \mathrm{Y}_{i,t} = \frac{1}{2}\left(\Delta ln Y_{i,t}^{t} + \Delta ln Y_{i,t}^{t-1}\right)$ where τ=t, t-1

The growth rate of a cost share weighted index of aggregate inputs can be expressed as follows:

(32) $\Delta \ln \mathrm{N}_{i,t}^{\tau} = [p_{i,\tau}^{L} L_{i,\tau} \Delta ln L_{i,t} + p_{i,\tau}^{E} E_{i,\tau} \Delta ln E_{i,t} + p_{i,\tau}^{M} M_{i,\tau} \Delta ln M_{i,t} +$

$c_{i,\tau}^{K} K_{i,\tau-1} \Delta ln K_{i,t-1} + c_{i,\tau}^{ICT} ICT_{i,\tau-1} \Delta ln ICT_{i,t-1}] / C_{i,\tau}$

(33) $\Delta \ln \mathrm{N}_{i,t} = \Delta ln N_{i,t}^{t} + \Delta ln N_{i,t}^{t-1}$ where τ=t, t-1

Since the number of parameters and components are many, and their relationships are complex, before analyzing the empirical result, a brief summary is provided for the different components definitions and their interrelationships as follows:

The technical change includes the process of innovation, invention and diffusion of technology. Adopting ICT and encouraging more innovation both in service and product and idea are examples to promote the technical change. The scale effect is about what happens to the demand of inputs when the firm expands its production. The temporary equilibrium effect is also called the market disequilibrium effect. It implies that rental prices do not reflect the marginal contribution of quasi-fixed factors into production.

The quasi-fixed factors’ marginal value products are different from their rental prices due to the presence of adjustment cost of quasi-fixed factors. Such differences between shadow prices and rental prices ensure the existence of market disequilibrium effects. If the adjustment of quasi-fixed factors to a long-run equilibrium is instantaneous, their rental prices would be equal to their shadow prices and the temporary equilibrium effect on the change of the TFP is zero. However, if the shadow prices are greater than rental prices, the existing stocks of quasi-fixed inputs are over-utilized, which implies that capacity utilization is greater than one. Any attempt to reach full capacity utilization induces an improvement in TFP and higher investment rates are positively related with the TFP and vice versa. The direct adjustment cost effect on the TFP change is uncertain.

It should be noted that when firms are investing in capital, they may need to divert resources to installing new capital rather than producing marketable output, which means that in periods of rapid investment growth, firms could be producing two types of products: The final product sold in the market, and the services used within the firm to install capital. Marketable output may therefore be lower in periods of high investment growth, and this would cause a downward bias in estimates of measured productivity growth.

The estimation results of the dynamic factor demand mode is reported in Table 6.1. The results are based on estimation of infinite planning horizon and non-static expectations for output, technology, and relative factor prices. The system equations include dummy variables for industry specific. These dummy variables capture the industry specific effects because the presence of heterogeneity across industries that cannot be explained by the production structure alone.

The Durbin-Watson test and White test revealed serial correlation and heteroskedasticity in the residuals. The variance-covariance estimator used for FIML is generalized least square estimator. The generalized least squares approximation to the Hessian is used in the minimization procedure (Nadiri & Prucha, 1990).

The parameters estimates satisfy the conditions of convexity of normalized restricted cost function in ICT and K, and the concavity in the variable input prices. The parameter estimates $a_{KK}, a_{\dot{K}\dot{K}}, a_{ICTICT},$ and $a_{I\dot{C}TI\dot{C}T}$ are positive, while a_{ll} and a_{ee} are negative. The hypothesis of the absence of adjustment costs for the quasi-fixed inputs K and ICT, $a_{\dot{K}\dot{K}} = 0$ and $a_{I\dot{C}TI\dot{C}T} = 0$ are rejected. Hence the static equilibrium model is inappropriate to describe the technology and the structure of the factor demand of the industrial sector in Korea (Nadiri & Prucha, 1986).

The demand for variable inputs depends negatively on their own normalized prices. The negative sign of quasi fixed inputs ICT capital and non-ICT capital in the labor demand function and in the energy demand function indicates that ICT capital and non-ICT capital are substitutes for labor input and for energy input. The significant coefficients for the industry dummy variables imply the significant differences in the cost structure across industries.

Table 6. 1

FIML Parameter Estimates for the Dynamic Factor Demand Model

Parameter	**Estimate**	**t Value**	**Parameter**	**Estimate**	**t Value**
$\mathbf{a_{kk}}$	0.097***	17.8	a_l	0.991***	18.08
	(0.005)			(0.055)	
$\mathbf{a_{koko}}$	1.952***	16.26	a_{ll}	-0.014**	-2.1
	(0.12)			(0.006)	
$\mathbf{a_k}$	-0.157***	-22.15	a_{el}	0.014***	3.99
	(0.007)			(0.004)	
$\mathbf{a_{lk}}$	-0.045***	-12.74	a_e	0.851***	29.47
	(0.004)			(0.029)	
$\mathbf{a_{ek}}$	-0.036***	-12.98	a_{ee}	-0.007***	-3.53
	(0.003)			(0.002)	
$\mathbf{a_{ii}}$	0.124***	32.41	a_0	0.948***	28.36
	(0.004)			(0.033)	
$\mathbf{a_{ioio}}$	1.334***	25.23	a_t	-0.002***	3.12
	(0.053)			(0.001)	
$\mathbf{a_i}$	-0.235***	-33.69	Ω_o	0.663***	55.38
	(0.007)			(0.012)	
$\mathbf{a_{li}}$	-0.076***	-11.37	Ω_1	0.011*	1.37
	(0.007)			(0.008)	
$\mathbf{a_{ei}}$	-0.060***	-13.63	Log Likelihood: **631.699**		
	(0.004)				

The scale elasticity can be calculated based on the estimated parameters Ω_o and Ω_1 and accordingly the returns to scale. Since the model is non-linear in both parameters and variables, the estimated parameters are difficult to interpret; hence the following measures are provided based on the parameters estimates.

6.5 Capacity Utilization Index

The temporary short-run equilibrium may occur in two ways: First, when unexpected demand shocks lead to under (or over utilization) of capacity, and second, when sudden changes in factor prices, such as the energy price shocks of 1973 and 1979, result in short-run relative factor usage, which is inappropriate for the long-run (Berndt & Fuss, 1986). One of the most common examples of temporary equilibrium is the existence of excess capacity, say due to a reduction in demand for output. Accordingly it is necessary to measure the capacity utilization along with the measure of the TFP in the presence of variation in capacity utilization.

The concept of capacity utilization has originated from the idea of a potential or capacity output. In the primal approach (the production approach) it refers to potential output as a maximum level of output when all factors are fully utilized, while the dual approach (the cost approach) considered the capacity output to be the optimal output level when cost is minimized with capital fixed in the short-run (J.-K. Lee, 1995). Following (Nadiri & Prucha, 1996) the capacity utilization measure can be defined based on the ratio of shadow cost to total cost, this measure is called shadow-valuation measure of capacity utilization. The total cost normalized by the price of materials is defined as follows:

(34) $C = M + p^L L + p^E E + c^K K_{t-1} + c^{ICT} ICT_{t-1} =$

$G(p^L, p^E, q^K, q^{ICT}, Y, K_{t-1}, ICT_{t-1}, \Delta K, \Delta ICT, T) + (1 + r_t) q^K K_{t-1} +$

$c^{ICT} ICT_{t-1}$

Where *G (.)* is the normalized restricted variable cost function defined in equation (8). The rental price of ICT and non-ICT capital are $c^{ICT} = q^{ICT}(r + \delta^{ICT})$, and $c^K = q^K(r + \delta^K)$, respectively. The shadow cost C^s is defined in equation (28). The capacity utilization measure, then, can be defined as the ratio of shadow cost to total cost:

(35) CU= C^s/C

The measure of capacity utilization according to equation (35) implies a deviation from unity, due to the quasi-fixity effect of capital in the short-run temporary equilibrium. The measure of the capacity utilization index is reported in Table 6.2 for three decades. As suggested by the production theory, a rise in the shadow price of capital relative to its market price would encourage production beyond capacity output (Hauver, Yee, & Ball, 1991). The measure of capacity utilization indicates optimistic investment for the last two period of the sample, as it is greater than unity indicating over utilization (Berndt & Morrison, 1981a; Morrison, 1986). The capacity utilization increase approximately 8% and 13% for the period 1990–1999 and 2000–2009, respectively, reflecting the 9% and 28% increase in output, respectively.

Table 6. 2

The Capacity Utilization Index for the South Korean Industrial Sectors by Decade

Year	CU index
1980–1989	0.965
1990–1999	1.045
2000–2009	1.196

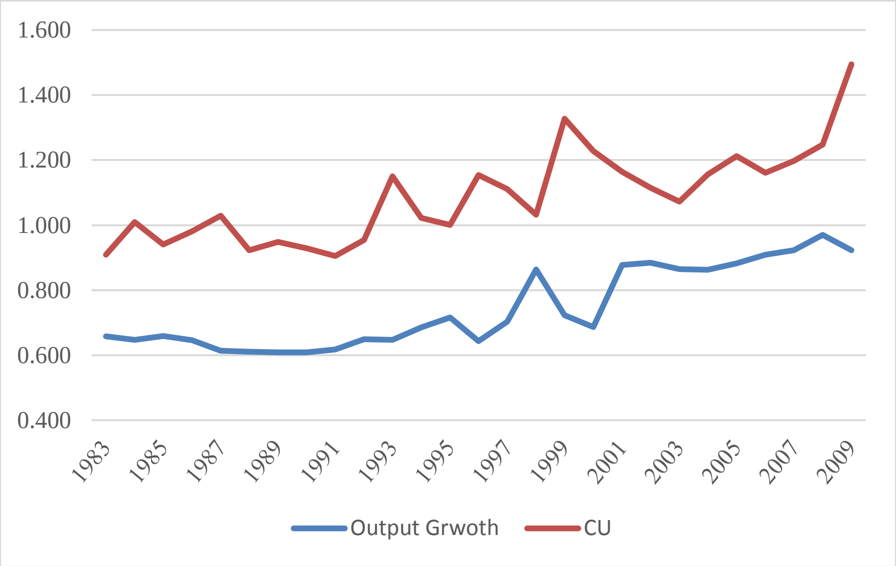


Figure 6. 1: *Development of Capacity Utilization Index and Output Growth by Year*

The capacity utilization Index including non-static expectations tend to be less than unity any time the industry is investing additionally in anticipation of, for example, output increases not justified on the basis of current economic conditions. The result indicates that production is to the right of the minimum point of the short-run average total cost curve, thereby indicating that the total cost is reduced by increasing the level of capital (ICT and non ICT) investment for the last two periods, while the total cost is increased with the increase in investment in during 1980–1989. The capacity utilization rate is increasing over time for the whole sample period (see Figure 6.1). For individual industry the measure of capacity utilization is reported in Table 6.3.

Table 6. 3

The Capacity Utilization Index for Individual South Korean Industrial Sectors

Sector	**CU**
Agriculture, Hunting, Forestry and Fishing	1.023
Mining and Quarrying	1.041
Food , Beverages and Tobacco	1.075
Textiles, Leather and Footwear	1.111
Wood and Cork	1.047
Pulp, Paper, Printing and Publishing	1.024
Coke, Refined Petroleum and Nuclear Fuel	1.107
Chemicals and Chemical Products	1.045
Rubber and Plastics	1.078
Other Non-Metallic Mineral	1.039
Basic Metals and Fabricated Metal	1.043
Machinery, NEC	1.083
Electrical and Optical Equipment	1.159
Transport Equipment	1.009
Manufacturing NEC; Recycling	1.101
Electricity, Gas and Water Supply	1.113
Construction	1.128
Sale, Maintenance and Repair of Motor Vehicles and Motorcycles; Retail Sale of Fuel	1.044
Wholesale Trade and Commission Trade	1.058

Retail Trade; Repair of Household Goods	1.081
Hotels and Restaurants	1.117
Transport and Storage	1.067
Post and Telecommunications	1.914
Financial Intermediation	1.056
Real Estate Activities	1.058
Renting of M&Eq and Other Business Activities	1.060
Public Admin and Defense; Social Security	1.014
Education	1.026
Health and Social Work	1.031
Other Community, Social And Personal Services	0.984

6.6 Price and Output Elasticities

The scale elasticity for the cost function (the scale economies) refers to the proportional increase in cost resulting from a small proportional increase in the output (or so called the elasticity of total cost with respect to output). If the calculated scale elasticity is less than unity then the situation is characterized as increasing returns to scale, implying economies of scale. On the other hand, if it is equal to unity then there is a constant returns to scale, if it is greater than unity then decreasing returns to scale, implying diseconomies of scale (Altunbaş, Gardener, Molyneux, & Moore, 2001).

As described earlier, the model specification in this study does not impose a priori constant returns to scale. Rather, it estimates the scale elasticity (represented by Ω_0 and Ω_1 in Table 6.1) from the data. For the South Korean industrial sectors there is a significant scale effects. The estimate for the average returns to scale is 1.5, but it differs across industries. This difference in scale elasticities will translate into substantial differences in the productivity growth.

The own- and cross-price elasticities of *L, E, M, ICT, I* and *K* for 1995 for the South Korean industrial sectors are reported in Table 6.4. The elasticities are calculated in forms of the short- and long-runs for each input. All of the own-price elasticities have the expected negative sign. The own-price elasticity of ICT is the largest among the inputs followed by *K, L, E,* and *M*. The short-run elasticity of variable input is defined when the quasi-fixed inputs are fixed while the long-run elasticity of variable input is defined when the quasi-fixed inputs have adjusted fully to their steady state levels.

In general the cross-price elasticities are smaller in comparison with their own-price elasticities. However, some of the elasticities are sizable. The elasticities of ICT with respect to the wage rate, price of energy, and price of materials are quite large in magnitude. The own price elasticities of all inputs except for ICT are inelastic (less than unity). There are differences between the short- and the long-run own price elasticities of all variable inputs, suggesting slow adjustment to long-run steady state levels.

Because ICT and non-ICT capital are treated as quasi-fixed factors, there is no adjustment in short-run, their short-run elasticities are reported to be equal to zero. In the long-run, the own-price elasticity of non-ICT capital demand is less than one, indicating that their demands are inelastic, but the own-price elasticity of ICT capital demand is greater than one implying elastic demand in long-run. ICT capital has a substitution relationship with energy and labor.

Table 6. 4

*Short- and Long-Run Price and Output Elasticities in the South Korean Industrial Sectors (1995)**

Elasticitities	Short Run	Long Run	Elasticitities	Short Run	Long Run
ε_{Lpl}	-0.12	-0.052	ε_{Kpk}	0	-0.3182
ε_{Lpe}	0.069	0.123	ε_{KpICT}	0	0
ε_{Lpm}	0.051	0.189	ε_{ICTpl}	0	1.334
ε_{Epl}	0.014	0.068	ε_{ICTpe}	0	0.812
ε_{Epe}	-0.006	-0.037	ε_{ICTpm}	0	-0.818
ε_{Epm}	-0.008	0.101	ε_{ICTpk}	0	0
ε_{Mpl}	0.011	-0.288	$\varepsilon_{ICTpICT}$	0	-1.328
ε_{Mpe}	-0.008	-0.244	ε_{KY}	0.070	0.076
ε_{Mpm}	-0.003	-0.605	ε_{ICTY}	0.081	0.086
ε_{Kpl}	0	0.554	ε_{LY}	0.37	0.37
ε_{Kpe}	0	0.352	ε_{EY}	0.06	0.07
ε_{Kpm}	0	-0.588	ε_{MY}	0.08	0.06

* ε_Z (Z=L,M,E,K,ICT) denotes the elasticity of factor Z with respect to p_L (wage rate), p_e(price of energy), p_m (price of material), p_{ICT} (rental price of ICT capital), and p_k(rental price of non-ICT capital)

The results are similar with the finding of G. Park and Park (2003) who argued that industries in South Korea have increasingly used ICT machinery to reduce the use of labor and thus the skilled-bias technological change is emerged. This means that the use of ICT will replace the low skilled labor but may create high skilled more complex job.

In analyzing the relationship between ICT and the job creation index, Hong (2012) showed that in South Korean service industries, increase in the ICT investment caused increase in the job creation. Furthermore, in her analysis of the relationship between ICT and the job loss index, she found that in ICT convergence industries, increase in the ICT investment will decrease the employment. Finally, in her analysis of the relationship between ICT and the net employment change index, she found that by increasing in the ICT investment, the number of new jobs added tended to exceed the number of jobs eliminated. Hence, the ICT net effect on the labor is positive.

The results are also in line with the finding of S. Park (2014) who compared the contribution of ICT capital in the industrial productivity for six countries: South Korea, US, UK, Germany, and Japan. He found that the contribution of ICT capital in the economic growth is lower in South Korea than in the other countries under the study. He further argued that there is sufficient potentials for economic growth based on ICT utilization. According to a study conducted by S. Park (2014), there may be two different sides of ICT capital utilization in the industrial production structure: First, a decrease in employment through the substitution of labor with ICT according to his finding about ICT-labor substitutability, and second, an increase in employment through economic growth driven by ICT capital.

The elasticity of ICT with repect to energy is larger in magnitude with the elasticity of energy with respect to wage rate, implying that ICT has a stronger substitutability chance with energy. Many studies in the fields of manufacturing and technical processes indicate that investing more in ICT capital substantially reduces energy input and consumption (Y. Cho et al., 2007; Erdmann & Hilty, 2010; Røpke & Christensen, 2012).

In a recent study, J. Kim and Heo (2014) disaggregated the energy input in the manufacturing, electricity, gas and water sector for three countries: South Korea, US, and UK, and by considering the relative price changes of input factors. Based on this disaggregation, they found that ICT capital substitutes the electricity and fuel consumption in the US and the UK manufacturing sectors. Although ICT capital, electricity, and fuel have substitution effects between each other in the South Korean manufacturing sectors, ICT capital is unlikely to decrease the demands for electricity and fuel when considering their relative price changes.

The long-run elasticities of the inputs are reflecting fairly sizable economies of scale. They exceed their short-run values. The patterns of the output elasticities indicate that the variable factors of production, labor, and materials, respond strongly in the short-run to changes in output. This is because labor, energy, and materials overshoot their long-run equilibrium values in the short-run to compensate for the sluggish adjustment of the quasi-fixed factors. They slowly adjust toward their long-run equilibrium values as ICT and non-ICT capital adjusts.

The positive output elasticity of energy suggests that the economic growth leads to higher rate in energy use. Although the economic growth can be helpful to productivity per unit of energy use, it increases the total energy use and CO2 emissions.

6.7 Returns to Scale

According to the obtained results, the production structure of the industrial sectors in South Korea is characterized by the patterns of factor input substitution and complementarity, as well as the degree of economies of scale. They are characterized by increasing returns to scale that substantially influences its productivity growth.

The results are in line with previous studies conducted by Kwack and Sun (2005), S. Park and Kwon (1995), and Nadiri (1993) who found similar results of scale economies and increasing returns to scale in the South Korean manufacturing sectors. However, other studies such as S. Kim and Han (2001), I. Oh et al. (2008), Khayyat (2013), and Khayyat and Heshmati (2014) based on different dataset and periods found constant returns to scale, and for some industries a decreasing returns to scale.

By looking at Table 6.5, where the returns to scale is averaged by decade, one can infer about the slide decreasing trend in the returns to scale over time (see also Table 6.2). This implies that the South Korean industrial sectors are moving toward efficiency in size and technical optimal scale level by succeeding to downsizing.

Table 6. 5

Technical Change and Returns to Scale by Decade

Years	**TC**	**RTS**
1981–1989	0.69	1.52
1990–1999	0.38	1.51
2000–2009	1.10	1.49
Whole Sample	0.72	1.5

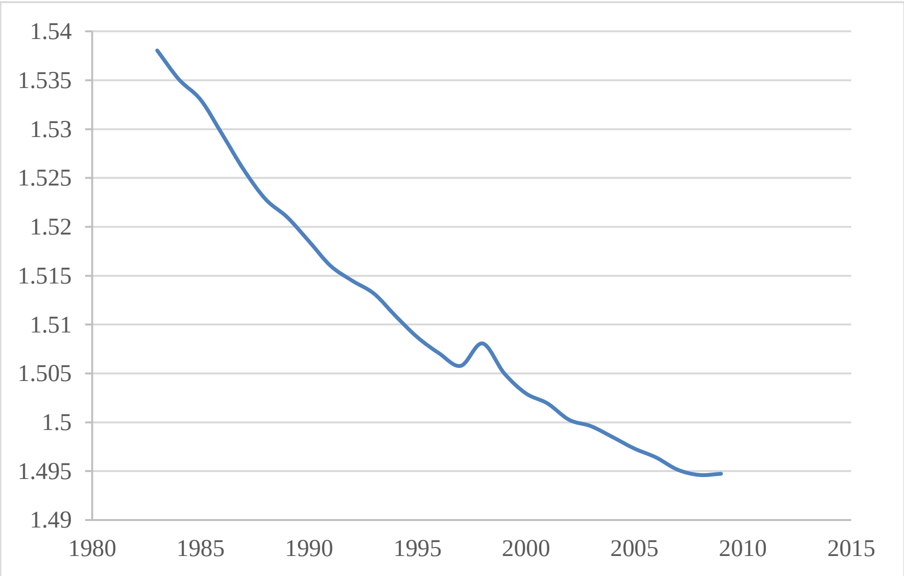


Figure 6. 2: *Returns to Scale by Year*

The returns to scale by industries are plotted in Figure 6.3. It is clear that some industries have relatively higher returns to scale than others. Electrical and optical equipment industry (code 13), Post and telecommunications industry (code 23), and Transport equipment industry (code 14) are the three industries with the highest values of returns to scale.

These three industries are classified as export based industries, industry code 13 and code 14 are high-tech industries, while code 14 is a mid-tech industry (see Table 4.5).

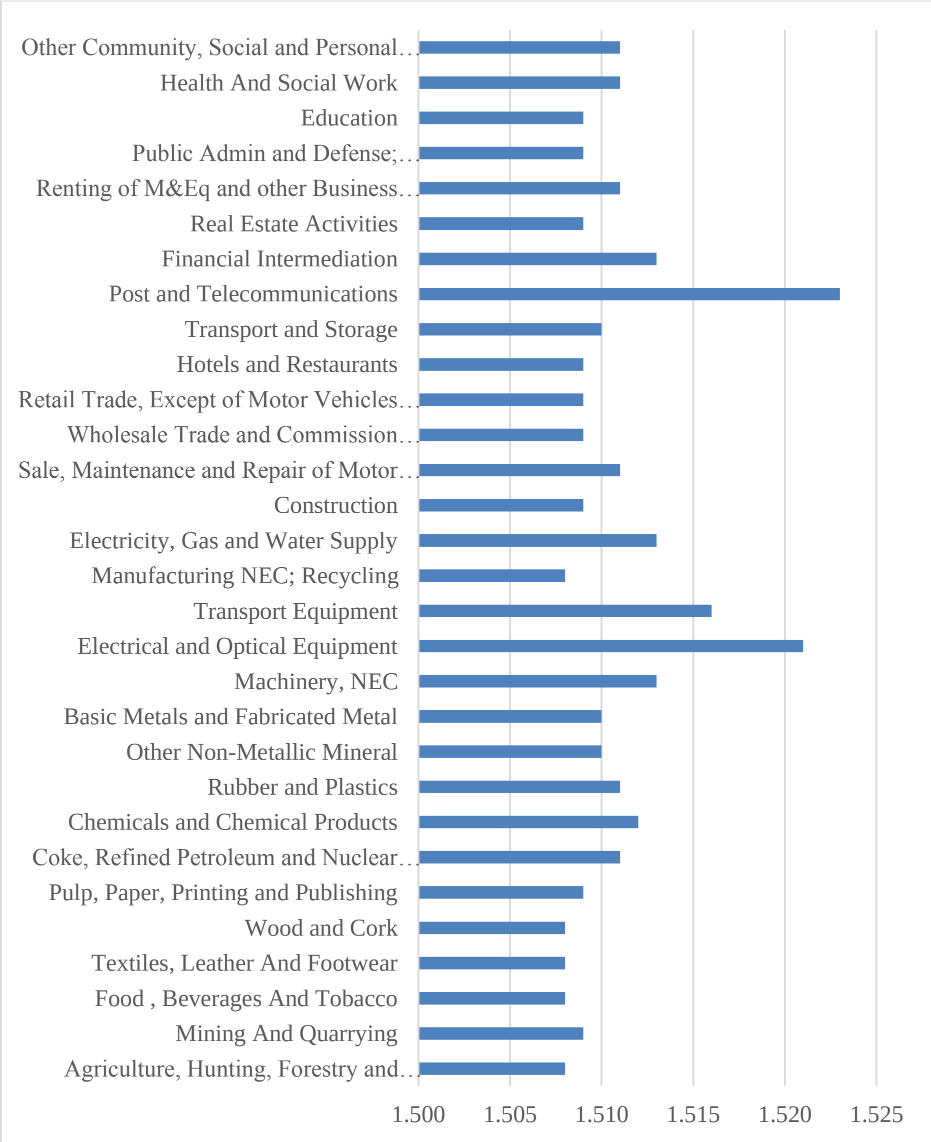


Figure 6. 3: *Returns to Scale by Industry*

According to Edwards (1992), many empirical studies showed that liberalization in trade has played significant role in the rapid growth of East Asian countries especially in South Korea. This evidence opened the door for wider discussions and further research, seeking to explain the link between the liberalization in trade and the economic growth. Two groups of literature are classified in this regards. The first group is the trade literature in which it provided two justifications for this link: First is the scale economies (Ethier, 1982; Krugman, 1994), and second is the pro-competitiveness for trade proposed by Krueger and Tuncer (1982).

The theoretical models related to the scale economies argument emphasize that trade allows for further utilization of scale economies that are limited by the size of the domestic market. The second group is related to the theory of "endogenous" growth appeared in the late nineteenth century. Their argument is that economies of scale, human capital accumulation, and technological progress are potential forces that make trade liberalization a driving engine for economic growth (A. R. Hwang, 2003).

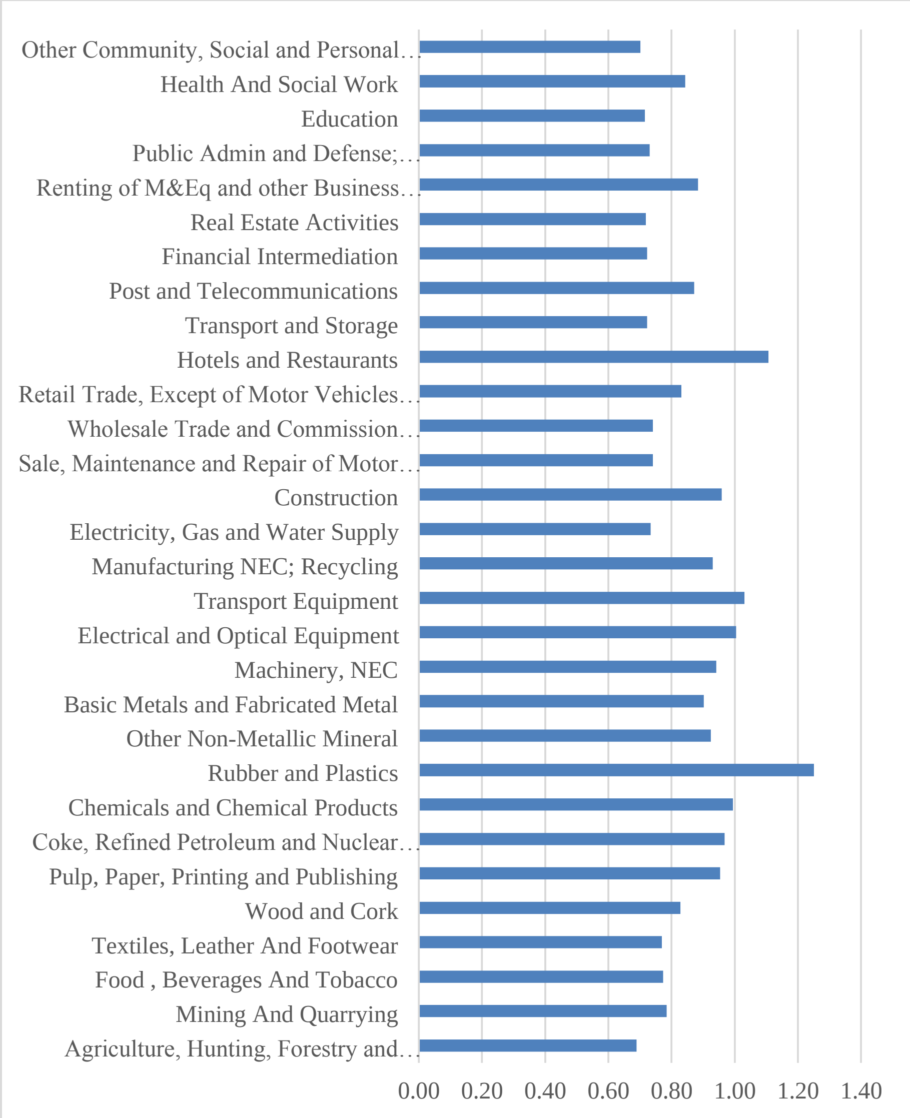
6.8 Technical Change

The rate of technical change is negative on the cost function. The average rate of the technological progress is estimated to be -0.69 %. This suggests that technological progress has led, on the average, to a 0.7 % reduction in the total cost per year. It is on the average decreasing from -0.7 % in 1980–1989 period to -1.0 % in 2000–2009 period. Kwack and Sun (2005) estimated on average the rate of technical change to be a 2 % reduction in the total cost for the period 1969–2000.

The industries seem to have Schumpeterian and neutral technical change too. The pure technical change represented by a simple time trend in the model suggests reduction of 0.2 % from the total cost (the coefficient of technical change represented by a simple time trend in the model is a_t= -0.002, see table 6.1). The overall mean rate of technical change on the cost function is decreased (for production function is thereby increased) during the analysis period (see Table 6.5). The rate of technical change did not show any smooth uniform pattern. It was rapidly increasing in 1990–1999 in the aftermath of the Asian Financial Crisis but showed another drop in 2000–2009.

The level of technology change is varied among industries (see Figure 6.4). Observing the first 10 industries with the highest rate of technical change[12], only two of these 10 industries are classified as low-tech industries, only three of them are domestic market industries, and only one with low scale R&D expenditure. This implies that the high-tech industries, export based industries, and industries with high R&D are in general technically more efficient than low-tech, domestic oriented market, and low R&D based industries, technology growth usually come from R&D.

[12] See Figure 6.4 and Table 4.5 for comparing between the industrial characteristics and the rate of technical change.



Note: The values of the technical change are taken as absolute values for illustration.

Figure 6. 4: *The Rate of Technical Change by Industry*

6.9 The TFP Growth

Based on the equations (21) to (27), the growth rate of total factor productivity ΔTFP is decomposed for different periods of time for the South Korean industrial sectors. As discussed previously the traditional measure of TFP will equal to technical change only if some assumptions were hold (i) producers are in long-run equilibrium when in fact they may be in short-run or temporary equilibrium, (ii) the technology is exhibiting a constant return to scale, (iii) input and output market are in perfect competition and (iv) factors are utilized in a constant rate.

The results are presented in Table 6.6. The growth of TFP has witnessed a slight increase (from 6.0 % to 8.0 % growth). The results indicate that the scale effect is by far the most important contributor to the TFP growth. The South Korean government pursued an industrial policy in order to promote the heavy and chemical manufacturing sectors during the 1970s. This policy tried to direct limited national resources into strategically chosen industries (mostly in chemical, basic-metal, and fabrication). One of the policy objectives was to enable firms to grow large enough to utilize scale economies and to compete in foreign markets (S. Kim & Han, 2001).

Table 6. 6

Decomposition of the Traditional Measure of TFP Growth (in percentage)

TFPT	TFPS	TFPE	TFPA	Divisia	Unexplained Residual
0.85	2.51	0.002	-0.037	6.98	3.65
(0.034)	(0.0813)	(0.008)	(0.033)	(0.236)	(0.151)

Years	TFPT Δ	TFPS Δ	TFPE Δ	TFPA Δ	Divisia Δ	Unexplained Residual
1981–1989	0.67	2.20	-0.010	-0.001	6.00	3.12
1990–1999	0.83	2.32	0.010	-0.080	6.29	3.21
2000–2009	0.99	2.92	0.003	-0.026	8.35	4.47

Many studies found that technical progress has been a key contributor to the TFP growth (Khayyat, 2013; Khayyat & Heshmati, 2014; S. Kim & Han, 2001). However this study found evidence of different results. The technical progress component of the TFP is very small (less than 1.0 %). The same is valid for the adjustment cost effect; the effects are negligible too, implying that there exists a slightly inefficient allocation of inputs in the production with a resulting decline of the TFP. The results show that the temporary equilibrium effect in South Korean industries is positive on average. However, it is noticeably small in magnitude.

By looking at Table 6.7 where the TFP is decomposed by individual industry, the estimated scale components in the TFP growth is relatively small for the following industries: Real estate activities, Transport and storage, Education, health and social work, Electricity, gas and water supply, Retail trade, retail sale of fuel, Wholesale trade and commission trade, and Hotels and restaurants. This implies that firms in these industries had already reached a certain size where scale economies no longer exist. These industries are characterized by domestic based trade industries.

According to the trade literature these domestic industries are limited in terms of growth in size, and hence the scale effect is relatively smaller in compare to export based industries where liberalization has its effects on growth in size (Edwards, 1992; Ethier, 1982; Krugman, 1994). For the same reason the export based industries have larger effects of scale on their productivity growth. These industries are Textiles, leather and footwear, Other non-metallic mineral, Food , beverages and tobacco, Machinery, NEC, Mining and quarrying, Pulp, paper, printing and publishing, Chemicals and chemical products, Rubber and plastics, Transport equipment, and Electrical and optical equipment. It implies that these industries are still growing in size in which scale economies matter for the growth. For the other industries, still the scale component is the largest component of the TFP. Thus, this study suggests that the prior industrial policy of exploiting economies of scale is still effective in promoting productivity in the industrial sectors.

Table 6. 7

Decomposition of the TFP by Sector (in percentage)

Industry	TFPT	TFPS	TFPE	TFPA	Divisia	Unexplained Residual
Agriculture, Hunting, Forestry and Fishing	0.69	2.71	0.000	-0.02	7.68	4.31
Mining and Quarrying	0.80	2.81	0.000	-0.05	7.79	4.22
Food , Beverages and Tobacco	0.77	2.72	0.000	-0.05	7.74	4.3
Textiles, Leather and Footwear	0.76	2.59	0.010	-0.07	7.31	4.02
Wood and Cork	0.82	2.77	0.010	-0.04	7.79	4.24
Pulp, Paper, Printing and Publishing	0.94	2.84	0.010	-0.04	7.96	4.22
Coke, Refined Petroleum and Nuclear Fuel	0.97	2.31	0.000	-0.04	6.38	3.13
Chemicals and Chemical Products	0.98	2.86	0.000	-0.02	8.00	4.17
Rubber and Plastics	1.22	2.91	0.000	-0.04	8.19	4.1
Other Non-Metallic Mineral	0.91	2.62	0.010	0.00	7.43	3.89
Basic Metals and Fabricated Metal	0.89	2.42	0.000	0.00	6.56	3.24
Machinery, NEC	0.93	2.78	0.000	-0.04	7.72	4.06

Electrical and Optical Equipment	0.99	3.76	0.050	-0.06	10.58	5.84
Transport Equipment	1.01	3.10	0.010	-0.01	8.68	4.57
Manufacturing NEC; Recycling	0.91	2.51	0.000	-0.06	7.15	3.79
Electricity, Gas and Water Supply	0.74	2.23	0.000	-0.06	6.07	3.18
Construction	0.94	2.37	0.000	-0.04	6.52	3.26
Sale, Maintenance and Repair of Motor Vehicles and Motorcycles; Retail Sale of Fuel	0.73	2.24	0.000	-0.03	6.15	3.21
Wholesale Trade and Commission Trade	0.74	2.24	0.000	-0.03	6.24	3.3
Retail Trade; Repair of Household Goods	0.81	2.23	0.000	-0.06	6.18	3.2
Hotels and Restaurants	1.05	2.26	-0.010	-0.08	6.28	3.06
Transport and Storage	0.73	2.01	-0.010	-0.04	5.50	2.8
Post and Telecommunications	0.87	2.34	-0.010	0.00	6.07	2.86
Financial Intermediation	0.72	2.56	-0.010	-0.02	7.24	4
Real Estate Activities	0.72	1.85	0.000	-0.07	5.00	2.5
Renting of M&Eq and Other Business	0.86	2.30	-0.010	-0.02	6.41	3.28

Activities						
Public Admin and Defense; Social Security	0.73	2.29	0.010	-0.05	6.38	3.4
Education	0.71	2.14	0.020	-0.03	5.70	2.86
Health and Social Work	0.81	2.20	0.000	-0.05	5.98	3.02
Other Community, Social And Personal Services	0.68	2.40	0.010	-0.02	6.61	3.54

The largest effects of technical change on the rate of productivity growth are observed in the following ten industries: Rubber and plastics, Hotels and restaurants, Transport equipment, Electrical and optical equipment, Chemicals and chemical products, Coke, refined petroleum and nuclear fuel, Construction, Pulp, paper, printing and publishing, and Machinery, NEC. Most of these industries are characterized as high-tech industries in which the technology is essential in the production process. Only two of these industries (Hotels and restaurants and Pulp, paper, printing and publishing) are characterized as low-tech industries. A possible explanation is that these two industries are striving to involve the technology in their production, aiming at higher productivity growth. The industries in terms of market orientation and R&D scale are mixed in results.

For the adjustment cost effect, the results show the following ten industries have the largest adjustment cost effect on decreasing the TFP: Transport and storage, Health and social work, Mining and quarrying, Food, beverages and tobacco, Public admin and defense, Electrical and optical equipment, Manufacturing NEC; Recycling, retail trade, Electricity, gas and water supply, Textiles, leather and footwear, Real estate activities, and Hotels and restaurants. These discrepancies in the adjustment cost effects on the TFP among the industries indicate that the degree of market distortion is varied across these industries. The results of inefficiency costs were generally lesser in the heavy and chemical industries (chemical, non-metal, and basic-metal), which the Korean government developed on a massive scale, than in other light manufacturing industries (food, and textiles). The level of government intervention was especially high throughout the 1970s onward but eventually declined during 1990s.

6.10 The Output Growth

The contribution of inputs, technical change, and adjustment costs to the growth of output are reported in Table 6.8. The decomposition is based on the approximation in equation (28). The average growth rate of total output is estimated to be 0.73% per year over the entire sample period. The contribution of various inputs to the growth of output is considerably different. The highest rate of the contribution is that of energy followed by labor and materials. Non-ICT capital has higher effect than ICT capital on the output growth given the share of ICT capital in the total capital is reasonable. The effect of technical change on output is 0.7 % on average. The results are consistent with a similar study by Pyo et al. (2007) who reported 9.04 as an average growth rate of output.

Table 6. 8

Decomposition of the Output Growth- Average Annual Rate of Growth (in percentage)

Years	Output Growth	Labor Effect	Materials Effect	Energy Effects	Non-ICT Capital Effect	ICT Capital Effect	Adjustment Cost Effect		TC
							Non-ICT Capital	ICT Capital	
1981–1989	6.35	0.51	2.58	2.69	0.05	0.05	-0.04	-0.02	0.69
1990–1999	6.86	0.67	0.75	3.03	2.4	0.03	-0.13	-0.16	0.38
2000–2009	8.78	0.85	3.47	3.07	0.05	0.18	-0.19	-0.11	1

6.11 Conclusion

In this chapter the production structure and the behavior of the factor inputs of production are modeled using a general dynamic factor demand model. The technology is modeled by a generalized restricted cost function for the homothetic case.

The model allows for multiple variable inputs and for quasi-fixed factors to become productive within a lag. It also relaxes the assumption of constant returns to scale; it is rather endogenously estimated in the model. A proper measure of technical change is introduced for technologies where some of the factors are quasi-fixed, and shows how these measures can be evaluated in terms of the restricted cost function.

The traditional measure of TFP growth is decomposed into technical change and other components that are attributable to scale effects and adjustment costs. In addition it was able to derive the sources of TFP growth for the South Korean industrial sectors during the period 1980–2009. These industries have experienced a high rate of output growth and weakly technologically progressive measured by the exogenous time trend technical change. The model allows for scale effects and the quasi-fixity of two input factors ICT and non-ICT capital. By including the ICT capital the model was able to capture the high technology characteristics of these industries. The South Korean industrial sectors experienced increasing returns to scale in which it positively affected the annual TFP growth. The technical change has a small positive effect on the growth compared to the scale effects. ICT and non-ICT capital showed substitutability pattern with energy and labor.

Chapter 7: Overall Summary, Hypotheses Test, and Policy Implications

7.1 Introduction

The analysis presented in chapter five and six provide an appealing perspective of the relationships between the energy demand and other input factors of production, especially the ICT capital investment, as well as between the energy demand and some industries' characteristics. It also provides a general comparison between these relationships through analyzing the productivity growth of the South Korean industrial sectors. This chapter will provide insights into the implications of all the factors affecting these relationships. It also provides an in-depth discussion of the results, along with a discussion of the limitations of this study and suggestions for future research. Recommendations for decision makers will be made, along with their support and justification that have emerged based on the findings.

By applying a dynamic factor demand model, this study provides a richer framework for the analysis of productivity growth than some of the more conventional approaches, by incorporating a dynamic aspect, non-constant returns to scale, and ICT capital as a quasi-fixed input of production. Quasi-fixed factors are characterized by internal costs of adjustment. The production possibility frontier depends on outputs and inputs, technology, economies of scale, and rates of change of the quasi-fixed factors. Omitting a dynamic aspect will typically generate inconsistent estimates of the technology parameters, and in turn, a misallocation in the decomposition of the measure of TFP growth. This study also deduced a measure of capacity utilization and explored the sources of bias for the traditional measure of TFP growth.

In this dissertation, a stepwise generalization for the dynamic factor demand model is applied. Two models of dynamic factor demand for the South Korean industrial sectors have been estimated. In the first model, the data has been split into subsamples by decade and based on the industries' characteristics (knowledge based and non-knowledge based). In discussing the various methods that allow for heterogeneity in the slope of parameters in a panel dataset, several approaches have been employed in the literature. Among them, one approach parameterizes individual slope coefficients as a function of observed characteristics (Browning, Ejrnæs, & Alvarez, 2010; Durlauf, Johnson, & Temple, 2005). This approach crucially depends on the specification of the functional coefficient and is subjected to potential misspecification problems (Baltagi, 2008).

Another approach is to estimate the individual slope coefficients using heterogeneous time-series regressions for each individual, which is only feasible in systems where the time dimension T is large. This method is not without criticisms, as the choice to pool the data and obtain a single estimate for the whole sample to estimate the equations separately for each individual, or to rely on the average response from individual time series regressions has been debated (For detailed discussion, see for example: Baltagi, Bresson, & Pirotte, 2008; Baltagi & Griffin, 1997; C. Hsiao, Pesaran, & Tahmiscioglu, 1999; Pesaran, Shin, & Smith, 1999). Hence to cope and incorporate both debates, this dissertation considers subsampling in the first model and considers the whole data sample in the second model.

Furthermore, the first model assumes constant returns to scale and benchmarks Japan for the sake of comparison. A number of extensions to the basic model are considered, including interactions of the variables with time and incorporating ICT capital investment as a quasi-fixed input, as well as a sensitivity analysis is conducted to find the proper model specification with stable productivity results. The second model is a more general model that determines the rate of returns to scale implicitly and then estimates the growth rate of TFP and the capacity utilization index. The decomposition of the growth rate of productivity is estimated by relaxing some of the standard assumptions. These are constant returns to scale, perfect competition in the market, and no internal costs of adjustment.

The terms in the decomposition correspond to the scale effects, deviations from the marginal cost pricing, adjustment costs, and the effects of changes in the quasi-fixed factors. Based on the estimation results, the TFP growth rate is computed and decomposed into its underlying components. Here the Divisia index of growth is compared with the technical change component of TFP. For the distribution analysis, first and second order stochastic dominance based on frequency and cumulative distribution of technical change, as well as the Divisia index and other TFP growth components are used.

By introducing internal adjustment costs explicitly into the firm's decision-making process, the estimated dynamic factor demand models yield optimal factor demands not only in the long-run, but also in the short-run. The introduction of adjustment costs is seen by many as a natural extension of the neoclassical theory of investment and production that permits a consistent modeling framework for both temporary and long-run equilibria (Nadiri &

Prucha, 1986). Hence, dynamic factor demand models provide a formal framework for tracing the evolution of investment and productivity growth over the short- and long-run. Imposing an *a priori* restriction on the production structure for the sake of simplicity may generate bias estimates of productivity growth, which may lead to a misdiagnosis of the sources of economic growth, among other problems (Nadiri & Prucha, 1986).

The approach used in this dissertation will help to shed light on the differences between non-parametric and parametric measures of the TFP growth, and also identify the causal sources. It systematically analyzes the data and extracts information effectively under rigorous testing and a sensitivity analysis procedure. It leads to a systematic evaluation of the data, based on the EU standard. The results will allow inference about its strengths and weaknesses, as well as suggest improvements.

7.2 The Research Questions and the Hypotheses

7.2.1 The research questions

The four research questions asked were as follows: (1) what is the relationship between the ICT capital investment and energy use in the production process of the South Koran 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 Koran industrial sectors, (3) how the structure of the South Korean industrial sectors' factor demand can be described, and (4) what is the major source of the TFP growth in the South Korean industrial sectors?

The corresponding hypothesis for research question 1 is as follows:

Hypothesis 1: The ICT capital investment and energy use have a substitutable relationship in the production process of the South Korean industrial sectors.

The corresponding hypotheses for research question 2 are:

Hypothesis 2: The level of ICT investment is lower than the optimal value in the production process of the South Korean industrial sectors.

Hypothesis 3: The level of energy use is higher than the optimal value in the production process of the South Korean industrial sectors.

The corresponding hypotheses for research question 3 are:

Hypothesis 4: The static equilibrium model is unable to describe the technology and structure of the factor demand of the industrial sectors in South Korea due to the presence of a dynamic adjustment cost for the quasi-fixed input factors of production.

Hypothesis 5: The South Korean industrial sectors exhibit constant returns to scale.

For research question 4, the hypothesis is:

Hypothesis 6: Technical change is the major source of TFP growth in the South Korean industrial sectors.

7.2.2 Hypotheses test

For the regression analysis, a variable is said to be significant if its p-value is less than (0.010) (highly significant), less than (0.050) (significant), or less than (0.100) (weakly significant). A regression analysis would determine the variables that would be included in the equation with the measure of coefficient of determination (R^2), a log likelihood ratio test, the level of significance (less than or equal to 0.05 percent), and specification tests that may vary according to the model type (Greene, 2008). In this dissertation, different specification tests are conducted for the choice of the independent variables and their interactions with a technology index represented by a simple time trend. They are compared and evaluated based on the significance levels and are theoretically validated.

In both specifications of the dynamic factor demand model, hypothesis 1 is supported. There is evidence of the substitutability pattern between ICT capital investment and energy use in the South Korean industrial sectors. In addition, both inputs have significant and positive effects on the rate of output growth during the sample periods.

The ICT capital is less than its long-run optimal values in all the periods under study, while energy use was less than the optimal for the first two periods of the sample but tended to be over used (by a large amount) in the last period, indicating, on average, a pattern of over use for energy. This supports hypothesis 2 and 3 that the level of ICT investment is lower than the optimal value, while energy is over used in the production process in the South Korean industrial sectors, respectively.

In both specifications of the dynamic factor demand model, hypothesis 4 is supported and the static equilibrium model is found to be inappropriate for describing the technology and structure of the factor demands of the industrial sectors in South Korea. This result is due to the values of the accelerator coefficients (m_{kk} and m_{ii}) being greater than zero, suggesting the presence of adjustment costs in the quasi-fixed input factors of production. The models specified in chapter 6 found that the average rate of returns to scale is 1.5, resulting in hypothesis 5 of constant returns to scale being rejected. Through the decomposition of the traditional measure of TFP growth, this dissertation found the main source of the productivity growth for the South Korean industries to be from the scale effects. This finding rejects hypothesis 6 that states that technical change is the major source of growth in the TFP in the South Korean industrial sectors. Table 7.1 provides a summary of hypotheses tested among the different models that were estimated in this study.

Table 7. 1

Hypotheses Tests among the Estimated Models

Hypothesis	Model 1	Model 2
H1	o	o
H2	o	o
H3	o	o
H4	o	o
H5	-	X
H6	-	X

Note: (x) for rejection and o for acceptation of the hypothesis.

(-) indicating that the hypothesis is not applicable to the model.

7.3 Summary of Results and Policy Implications

The main results of this study can be summarized as follows:

1. The production structure of the South Korean industrial sectors is characterized by increasing returns to scale. The responses of the factors of production to changes in factor price and output are similar in the short- and long-run (with small differences in magnitude). In both the short- and long-run, ICT capital investment has a substitution pattern with energy use and labor, but a complementary pattern with respect to materials. Energy use has a substitutable relationship with materials and labor. ICT and non-ICT capital are found to be quasi-fixed and their speeds of adjustment vary. Energy use has a substitutability relation with materials and labor. ICT and non-ICT capitals are found to be quasi-fixed and their speeds of adjustment vary.

2. The stock of ICT capital investment adjusts faster than the stock of non-ICT capital, implying that the South Korean industries are still capital-intensive. The ratio of actual energy input to the optimal value was negative for the first two periods of the sample, but was positive (indicating overuse) during the last period. Table 7.2, which provides the energy intensity indicator, shows that there was a steady decline in the energy intensity of South Korean industries, falling at an average rate of 85%, from the period 1980–1989 to the period 1990-1999. The energy intensity slightly increased in the last period of the sample (See also Figure 7.1). Despite this decline in the energy intensity, it is expected to remain above the level of all the IEA countries. South Korea's target of a 30%

reduction in emissions lead the government to pursue a series of aggressive energy policies directed at energy efficiency (IEA, 2012).

The South Korean government is continually transforming its economy from a large, energy intensive, industrialized one that contributes less to the value added to one with lighter, higher-tech industries that consume less energy but contribute more to the value added (Eichengreen, Dwight, & Kwanho, 2012).

The energy figures for the first two periods of the data sample reported in Table 7.2 conform to the policy mentioned above, but the last period (i.e., 2000-2009) shows that the energy use has dramatically increased by 11 % from the optimal level. The pattern of substitutability between ICT capital and energy use (as found in this study) will help to overcome this issue. There is still room for a more detailed investigation into why ICT lowers the energy intensity in the South Korean industrial sectors (the value added figures by individual industry is reported in Table 7.3).

Table 7. 2

Growth in Value Added and Changes in Energy Intensity at the Aggregate Economy Level by Decade

	Average Annual Growth rate		
	1981–1989	**1990–1999**	**2000–2009**
Energy Intensity	1.74	0.94	0.99
Value Added	2.73	1.95	0.74

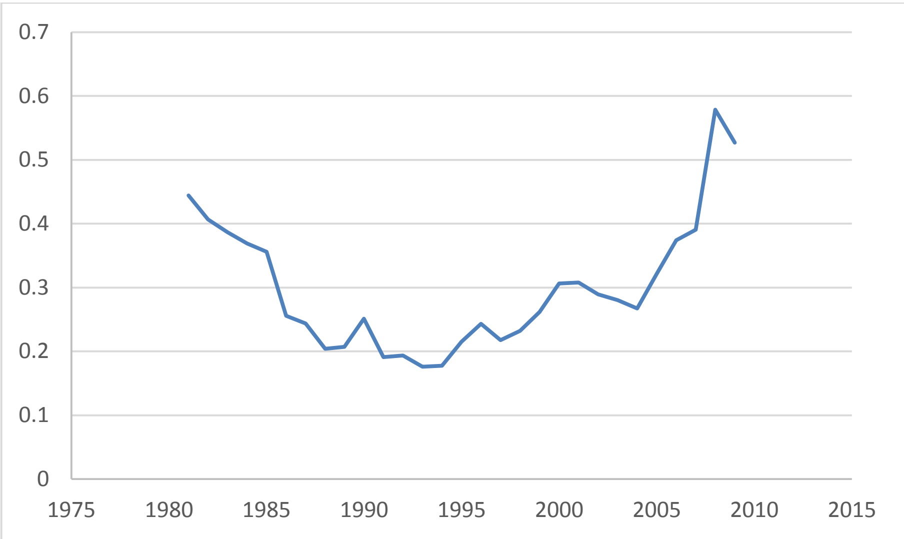


Figure 7. 1: *Average Energy Intensity by Year*

Table 7. 3

Growth in Value Added and Changes in Energy Intensity at the Aggregate Economy Level by decade and by Industry

	Energy Intensity (ratio of energy to VA)			**Growth in Value added $(z_t - z_{t-1})/z_{t-1}$**		
Sector	**81–89**	**90–99**	**00–09**	**81–89**	**90–99**	**00–09**
Agriculture, Hunting, Forestry and Fishing	0.86	0.79	1.24	0.89	0.65	0.01
Mining and Quarrying	1.32	0.78	1.04	0.51	0.42	0.46
Food , Beverages and Tobacco	2.50	1.16	0.75	1.62	1.66	0.40
Textiles, Leather and Footwear	1.68	1.09	0.73	1.36	0.75	-0.26
Wood and Cork	1.82	1.03	0.88	1.91	1.38	0.34
Pulp, Paper, Printing and Publishing	1.18	0.84	1.09	2.98	1.79	0.23
Coke, Refined Petroleum and Nuclear Fuel	0.58	0.50	1.23	1.99	6.97	0.38
Chemicals and Chemical Products	1.50	0.90	1.02	2.31	1.87	0.86
Rubber and Plastics	4.40	1.76	0.54	4.24	2.09	0.59
Other Non-Metallic Mineral	1.22	0.87	1.06	3.00	0.86	0.52
Basic Metals and Fabricated Metal	1.44	0.85	1.00	3.73	1.65	0.96

Machinery, NEC	1.56	1.22	0.90	4.94	1.16	1.61
Electrical and Optical Equipment	2.11	1.43	0.87	3.61	3.17	0.51
Transport Equipment	1.64	1.19	0.92	4.20	2.08	1.28
Manufacturing NEC; Recycling	2.03	1.22	0.71	2.83	0.96	0.49
Electricity, Gas and Water Supply	0.44	0.48	1.33	2.41	2.33	0.24
Construction	2.70	0.94	0.93	2.99	1.28	0.71
Sale, Maintenance and Repair of Motor Vehicles and Motorcycles; Retail Sale of Fuel	0.98	0.84	1.06	1.66	1.64	0.59
Wholesale Trade and Commission Trade	0.98	0.84	1.08	1.87	0.88	0.51
Retail Trade; Repair of Household Goods	1.01	0.84	1.08	1.88	1.05	0.47
Hotels and Restaurants	2.76	1.10	0.83	3.41	2.04	0.58
Transport and Storage	0.40	0.42	1.28	1.34	1.74	0.52
Post and Telecommunications	0.79	0.68	1.13	3.40	2.31	0.63
Financial Intermediation	2.59	0.94	0.96	3.53	2.78	1.16
Real Estate Activities	0.26	0.62	1.15	2.89	3.22	0.36
Renting of M&Eq and Other Business Activities	3.56	1.19	0.89	4.57	2.80	1.08

Public Admin and Defense;Social Security	0.97	0.85	1.05	1.72	2.12	1.04
Education	1.62	0.66	1.08	2.48	2.04	1.16
Health and Social Work	5.92	1.16	0.76	4.62	2.76	1.70
Other Community, Social And Personal Services	1.46	0.89	1.02	2.88	2.02	3.12

3. The results of the decomposition of the growth of TFP indicate that technical progress is not the main driver of the TFP growth. The results are in line with the finding of a study conducted by S. Jung (2011) that analyzes TFP growth for South Korea's ICT industries using a stochastic frontier production approach that compares the results to the major industrialized countries. His finding reveals that in the manufacturing sector of ICT (in South Korea), the TFP growth rate in the 2000s has been significantly lower than that of US and Japan. The author believes that this lower growth of TFP is due to a continuous decrease in technical efficiency. However, the gross output and the TFP growth for the South Korean ICT service sector were both found to be above the average level of developed countries, even though technical progress is lower than those of developed countries.

4. The TFP growth for the South Korean industrial sectors is likely to be positively affected by economies of scale, suggesting a serious bias of the conventional measure of the TFP growth. The technical change has a small, positive effect on growth. The results of the TFP decomposition indicate that South Korean industries have reached a level of technological sophistication from where it is difficult to make substantial, additional progress. For the period 1980s onward, the policy focused on the growth in foreign direct investment (FDI) with a concentration on technology based industries as a source for economic growth.

   The technology policy encouraged the private sector to innovate and invest in R&D, and also called for the collaboration between the ministries' R&D

activities (P. Park, 2000). The 1990s were a period of continuously supported FDI with a concentration in technology as a source of economic growth and an enhancement in the innovation capabilities of the private sector. The globalization era of the 2000s was the last stage of economic growth in South Korea, where growth was mainly from technology, innovation, and the building of the national innovation system, during which R&D investment sharply increased (P. Park, 2000). This led to the hi-tech sectors being encouraged to internationalize. This period was characterized by highly advanced technology, ICT, bio-technology, and R&D collaboration. According to OECD Science, Technology, and Industry Scoreboard 2013, South Korea ranked second among the OECD countries in terms of R&D spending to gross domestic product. South Korea's R&D spending versus its GDP stood at 4.03 % (OECD, 2013).

Many scholars emphasized the complementary relationship between R&D spending and ICT investment and the role of both in productivity growth (Hall, Lotti, & Mairesse, 2013; Polder, Van Leeuwen, Mohnen, & Raymond, 2009; van Ark et al., 2003). By looking at Figure 7.2 and Table 7.4, the correlation between R&D expenditure with ICT capital is noticeably high, indicating that more investment in ICT is a result of more R&D expenditure.

Table 7. 4

Correlation Coefficients of ICT Capital and R&D Investment

Year	ICT	R&D	Year	ICT	R&D
1980	0.078	0.011	1996	1.046	0.882
1981	0.087	0.018	1997	1.296	0.971
1982	0.097	0.029	1998	1.308	0.862
1983	0.114	0.05	1999	1.367	0.917
1984	0.144	0.072	2000	1.501	1.102
1985	0.169	0.102	2001	1.589	1.29
1986	0.198	0.135	2002	1.671	1.382
1987	0.236	0.164	2003	1.728	1.559
1988	0.302	0.212	2004	1.791	1.838
1989	0.336	0.246	2005	1.865	2.007
1990	0.347	0.296	2006	1.956	2.275
1991	0.424	0.368	2007	2.062	2.539
1992	0.504	0.454	2008	2.15	2.773
1993	0.599	0.563	2009	2.226	2.969
1994	0.695	0.66	2010	2.302	3.468
1995	0.81	0.785	**Correlation Coefficient**	**One lag: 0.949(t=1)** **Two lag: 0.951(t=2)**	

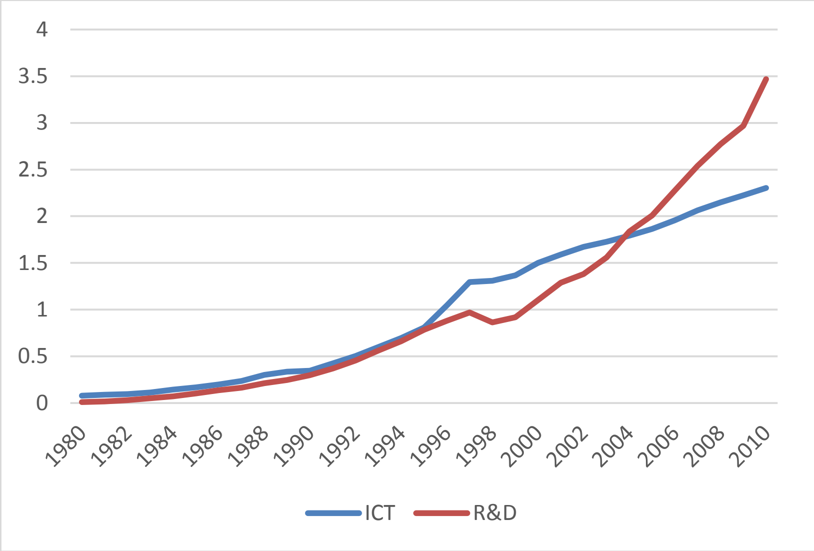


Figure 7. 2: *Correlation between ICT Capital Investment and R&D Investment*

5. The above-mentioned policies reveal the refocusing of the South Korean industrial strategy from a consumer industry to a heavy and chemical industry, and then to a technology intensive industry. For an individual industry it may still be possible to improve efficiency by catching up relative to the best practice frontier of the industry globally. When this possibility is exhausted, the total factor productivity change for the industry may come to a halt.

6. The temporary equilibrium effect is another source that promotes TFP growth. A positive, temporary equilibrium effect indicates that, on average, the rental prices of quasi-fixed inputs are less than the shadow prices, implying that quasi-fixed inputs are over utilized. Increasing investments in ICT capital may enhance the competitiveness of the South Korean industries relative to the rest of the world. The results of the scale effects experienced by South Korean industries suggest that the growth strategy of the industries should no longer focus on expansion, with regards to size.

7. The unexplained residual source of the TFP (an average of 3.6%) may come from the assumption of perfect goods and factor markets, as well as possible errors in the measurement of inputs. Previous studies by Kwack and Sun (2005) and Berthélemy and Chauvin (2000) found the unexplained residuals of the TFP to be 1.3% and 1.2%, respectively. This result is in line with Huggett and Ospina (2001), who find the effect of purchases of new technology equipment initially to reduce the TFP growth.

   The unexplained residual may then be attributed to the less than full utilization of some of the imported capital goods, especially the imported high-tech equipment, owning to their technological sophistication that was beyond the Korean knowledge of the technology. Additionally, over-investment and idle imported capital equipment raised the cost of capital and their contribution to output, and as a result, the productivity did not fully materialize as it negatively affected the TFP growth (Kwack & Sun, 2005).

   It is recommended that in order to analyze the unexplained portion of TFP, new models need to be developed that incorporate other factors explaining the decomposition of the TFP, such as dividing the labor into high, medium, and low skilled labor and considering the high skilled labor as a quasi-fixed input.

8. There is a significant contribution of ICT capital in both output and labor productivity growth when considering the rate of ICT capital in the capital investment ratio.

9. South Korea's export-orientated industrial sectors policy has been successful, suggesting that their energy efficiency in the industrial sectors

is high when compared to other developed countries. This result supports the claim of the IEA (2012) report. However, there is room for further improvement. For example, greater clarity on specific targets (including sector-specific targets), clear complementary plans and time schedules, and greater coordination and co-operation among government ministries and agencies are needed.

As recommended by the IEA (2012), South Korea may also be capable of strengthening its efforts to improve data collection and the analysis of monitoring and evaluating the results of the impact of energy efficiency policies across all sectors in its economy. Industries with energy intensive patterns and electricity generating plants are considered to be a significant potential for waste heat recovery and combined heat and power operations. The recent initiation of the district heating system implemented by the South Korean government to supply 1.8 million households has already started to utilize the efficiency of energy use. South Korea should explore further opportunities in this sector, including the use of recovered waste heat in district cooling systems to displace electricity usage during summer peaks in the electricity system. Policies toward the reduction of energy use and adoption of demand restraint measures may further enhance energy efficiency policies and to achieve higher rates of energy independence, which is considered to be a key factor in the green growth strategy.

7.4 Implications for Industry and Policy Makers

The findings of this dissertation should be of interest to the industry. This study is the first of its kind to evaluate the production structure in the South Korean industrial sectors applying a dynamic factor demand model. Furthermore, the dataset used here is the most extensive one used for productivity studies of the South Korean industrial sectors, both with respect to the length of time period and the number of industries studied. This implies that conclusions can be drawn with higher confidence than if one merely relies on observations from an individual, aggregate industry. However, caution is required in the interpretation of the results due to the quality of the data.

There are number of ways industries can reduce their energy consumption. Improvements in the industrial process (especially in processing heat) may lead to a reduction in energy waste, as well as provide a way to recover energy. Materials recycling and fuel inputs are also considered factors for energy efficiency improvement. Policy makers and stakeholders may take these efficiency opportunities into account when making decisions.

According to the empirical results obtained from this study, increasing the level of ICT capital may reduce the energy demand due to substitutability effects. This finding suggests that producers should invest more in ICT and digitalization, as well as R&D in order to reduce their demand for energy. It also supports the finding that ICT capital is a substitute for energy inputs in most sectors over time.

For public research programs aimed at the industrial sector, an implication of the empirical results is that one should be concerned about the dynamic aspect properties in research on new technologies and in investigating possible alternative inputs for energy. The result suggests that technical progress contributes less than the returns to scale in estimating a dynamic factor demand. However, it is an open question as to what extent this development has been driven by the producers compared to government sponsored research and development.

7.5 Country Specific Implications

7.5.1 Petroleum sector in the Kurdistan region of Iraq

a. Recent trends in the oil and gas industry

The Kurdistan Region of Iraq and the Kurdish people have waited for a long time to control and manage its oil and gas resources. The peace and relatively high security in the Kurdistan Region of Iraq, compared to other parts of Iraq, have enabled the Kurdistan Regional Government (KRG) to develop its oil and gas sector, as well as contract out much of its land to international resource exploration and energy production companies based on production sharing agreements schemes (see Figure 7.3).

The Kurdistan region of Iraq, located in northern Iraq, is rich in natural resources. The region has estimated reserves of 45 billion barrels of oil and 3–4 trillion cubic meters of natural gas (Mearns, 2012). The first foreign oil operator to enter the Kurdistan region of Iraq was the Norwegian DNO to explore for oil in 2009. After the discovery of a significant volume of oil in other fields, the Kurdistan region of Iraq has become the host for an increasing number of oil companies, forming the basis of the region's infant oil industry. The efforts of the KRG, combined with the large volume of reserves, have attracted a large number of international oil companies to invest in the expansive oil industry.

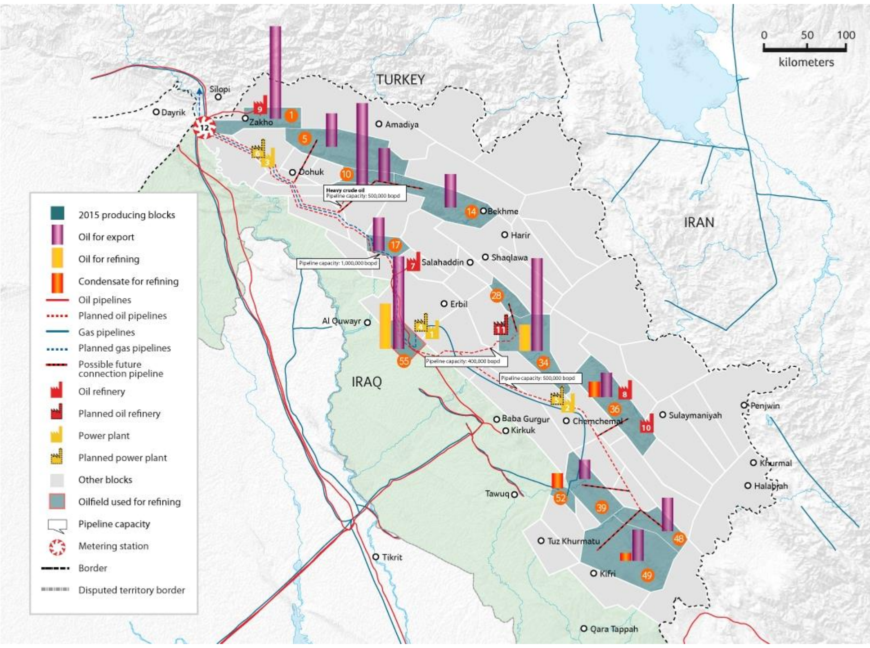


Figure 7. 3: *Discoveries and development of 'blocks' in the Kurdistan Region of Iraq*[13]

Unlike the political dispute between the KRG and the Federal Iraqi Government, the KRG pursues a set target with respect to developed investment conditions in its oil fields. This can be considered a golden opportunity for the economic improvement in the region by generating more resource revenues. The main question is how the KRG can handle the

[13] Source: KRG Ministry of Natural Resources "http://mnr.krg.org/index.php/en/".

political, economic, social, environmental, and security challenges so that the abundance of nature resources can be a ‘blessing’ and not ‘curse’.

The flood of oil income may develop the economic sector regionally and also globally with positive spillover effects on neighboring regions in Iraq. However, there is a danger associated with the emerging symptom of ‘resource curse’, which can deteriorate the agricultural and infant industry sectors, and also result in the dependency on oil income. This could result in the Kurdistan region of Iraq hosting the consumption of a larger percentage of imported goods and services. Such a tendency has already been observed. Therefore, better management of the oil and gas sectors can play a major role in transforming there region into a well-developed region and a model for reconstruction for the rest of Iraq.

According to the KRG Ministry of Planning, the region experienced different growth rates in the non-tradable sectors in 2007: Transportation, telecommunications, and storage (57%); Social and personal development services (22.7%); Wholesale and retail (8%); Tourism and hotels services (7%); Agriculture (5.6%); Building and construction (4%); Finance and insurance (1.5%); and Mining and quarries (0.1%). The different sectors show highly heterogeneous growth patterns. The highest growth rate (57%) between 2004 and 2006 was that of the Transportation, telecommunication and storage sector.

The petroleum sector in the region may require a comprehensive and multidimensional research study to be conducted covering the economic, political, environmental, legal, technological, and social aspects in order to identify the weaknesses of the oil and gas institutional structures. The present institutions responsible for the oil and gas sector are suffering from a lack of separation of roles. This can cause severe negative effects on the decline in oil income in the long-term. Learning from the successes and failures of other oil producing countries in order to develop better management of oil and gas can be useful. The Kurdistan region of Iraq is a newly extractive 'de facto' state that urgently needs to train and attract domestic high skilled human resources to the petroleum fields, in order to actively participate in the improvement of the oil and gas industry, as well as to be able to manage it effectively.

b. The oil and gas sector development and their contributions

It is expected that the abundance of resources and their exploitation will provide the economic sector with the much needed capital investment and advancements in technologies and management that are preconditions for sound economic growth. Conversely, it has been observed that resource rich countries have experienced low economic growth compared to the resource poor countries (Sachs & Warner, 2001).

The Kurdistan region of Iraq's oil and gas sector has not yet been well developed, and the refinery industry sector, as well as other infrastructures and components, are still under development. The output of the oil and gas sector is the other way that the resource sector contributes to the economy in the region. This refers to the physical output from the petroleum (oil and gas) sector, which feeds other parts of the economy. For example, crude oil is an input into the refining, petrochemical, and electricity production and energy intensive industries. The oil and gas sector generates production in the manufacturing sector, which leads to an increase in non-oil exports and a higher degree of self-sufficiency.

Similar to newly industrialized and developing countries, the resource sector can contribute to the economics and social development of the region through the identification, acquisition, adaptation, and assimilation of imported technologies, as well as the training of human resources in various technical fields of the industry. This requires careful planning and the implementation of different policies than the current business driven development policy. It is important to provide profitable business opportunities to corporations, but high priority should be given to the public and national interest.

7.5.2 Policy implication

The main challenge facing the petroleum industry in the Kurdistan region of Iraq is to ensure the sustainability of the supply of oil from, not only the existing but also new oilfields and other fossil energy sources. This sustainability will play a major role in avoiding future oil crises. Strict market conditions, such as the lack of adequate spare productive capacities in the oil production and refinery processes, will keep the oil price high and make upgrading and improving the supply an urgent need (United Nations Conference on Trade Development, 2006).

The structure of the oil industry in general is characterized by a capital intensive and skilled based nature that makes ICT a possible instrument to facilitate the modernization of the sector. Hence, heavy investment and the efficient use of ICT will contribute to the possible improvement of the oil sector. Computing, measuring, and communicating devices embedded in modern oil technologies are making the oil sector a more ICT intensive sector.

The production of oil in general is mainly concentrated in developing countries where the oil industry technology standards are similar to those in advanced countries. The impact of ICT on improving the economic performance of the oil sector will affect the production of crude oil. The use of ICT for efficiency gain will benefit both the upstream level, represented by exploration and production, and the downstream level, represented by transportation, refining, and distribution.

7.6 Conclusions and Practical and Policy Recommendations

It is believed that the results from this study, derived from different specifications and models for production and energy demand, will be useful for future empirical studies in this field of research. The empirical results have made it possible to evaluate how well energy conservation can be achieved in each individual industry in South Korea and to suggest guidelines concerning policy formulation and evaluation to further enhance energy use efficiency at the industry level.

Energy prices and environmental problems are major constraints on the development in different industries. Maximizing energy efficiency should be consistent with the public industrial development strategies. However, it is not always clear which choice will be made when considering the pursuit of greater intensive developments or less intensive strategies. This dissertation will help to shed light on how differently a certain policy affects each industry.

The South Korean Energy Vision 2030, unveiled in November 2006, was a comprehensive government policy package aimed at providing energy for a more dynamic Korea. Authored by the Ministry of Commerce, Industry, and Energy (MCIE), the long-term program features three basic directions, five objectives, and nine key tasks The Vision’s three basic directions include energy security, energy efficiency, and environmental protection, while the five objectives are the realization of an energy self-sufficient nation, conversion to a lower energy-consuming society, elimination of South Korea's high level of dependence on petroleum, realization of a mutually supporting, open society, and transition of South Korea to a major exporter of energy-related equipment and technology. The MCIE suggested a long-term plan for energy and aimed at the ultimate goal of improving energy efficiency.

The second national energy plan, issued in January 2014, has changed the policy direction from protecting the energy industry to requiring a paradigm shift in the policy direction. The paradigm shift includes changes in the policy goals, market system, international relations, and puts an emphasis on technology development, in the hopes of increasing competitiveness. The energy policy to pursue a new goal of "sustainable development" takes into consideration economic growth, the environment, and energy security factors. One of the essential policy directions is that energy prices and the demand and supply will be led by a market system rather than the government’s intervention as was the case in prior years.

Another vital change in the policy involves the emphasis on global market competition, with the competitiveness of the energy industry intensively depending on the ability to develop internationally competitive technologies with which new markets can be cultivated. The monopolistic system of the past hindered the individual entities motivation to innovate and develop advanced applied technologies. The government was taking the initiative in developing common-basic technologies that fit with domestic demand conditions[14].

Expending energy conservation and efficiency in the industry play key roles in improving energy security and environmental sustainability. Furthermore, it is one of the most cost-effective instruments for reducing energy imports, as well as an important strategy to mitigate climate change. However, industrial energy consumption in South Korea is largely concentrated in the three largest energy-intensive (chemical, non-metallic mineral, and metal) industries. The energy consumption in these industries accounts for roughly 80% of the total energy consumption in the manufacturing industries since the late 2000s. As of 2007, the overall Korean energy import dependency stood at nearly 97%.

What was the energy intensive industrial structure attributed to? Starting as one of the least industrialized countries in the world, with GDP per capita at $80 in 1960, South Korea has grown rapidly, with GDP per capita increasing to over $20,000 in 2010. South Korea has been characterized by not only its rapid economic growth, but also by its sharp increase in energy

[14] The detailed national energy plan can be found at the Korean Energy Economics Institute website:
"http://www.keei.re.kr/main.nsf/index_en.html?open&p=%2Fweb_keei%2Fen_Issues01.nsf%2Fview04%2FA7C6A48CA75D4CAE49256E2900483FAD&s=%3FOpenDocument".

consumption. Energy policy directions led to rapid increases in energy use. They were mainly focused on providing stable and reliable supplies of energy at low prices, with the aim to enhance industrial and national competitiveness. The government did not make necessary efforts to switch the industrial structure to lower energy use or high energy efficiency. In order to change the energy-intensive industrial structure, energy should be supplied by the energy markets rather than through government intervention. This would help to enhance energy efficiency and reduce energy use. The supply policy of a low price for industrial energy is a similar concept to giving a subsidy to the energy-intensive industries. The government should instead promote energy savings or the enhancement of energy use efficiency by supporting technology development funds and the provision of tax incentives.

The IEA has produced several reports on international and industrial comparisons of energy efficiency, but they acknowledge that there are multiple interpretations of energy efficiency. Informational, analytical, and institutional development measures are needed to make supportive policies, but the lack of a consensus intensifies the confusion about the efficient use of energy policy. Energy efficiency concerns the relationship between the output of a device and the energy put into it. For instance, an automobile's energy efficiency is often expressed in units of fuel/km. Here, the definition of improved energy efficiency is using less of the energy input. However, the national economy is too wide and complicated to be explained by the energy/GDP ratio. In order to achieve the goals of energy policy, one must first have a strong measurement system that can evaluate the level of energy efficiency objectively and regularly. In this regard, this study could contribute to the development of the desired measurement tool through the decomposition of the components of TFP growth.

7.7 Limitations of the Study and Recommendations for Further Research

Based on the findings of this dissertation, it is believed that this quantitative study increased the reader's knowledge about the structure of production technology in general, as well as the energy demand structure of the South Korean industrial sectors in particular. In addition this study has contributed to the discussion of model specification and estimator choice for empirical modeling of factor demands. The model allowing for non-constant returns to scale, incorporating ICT capital as an exogenous factor input, and incorporating dynamic aspects provided a richer framework for the analysis of productivity growth, all advantages over the other conventional approaches.

However, this study has its limitations as well. In the course of the research work, several interesting paths were not entirely investigated, as the scope of the analyses would otherwise be too wide and perhaps less accurate. A number of issues may remain unobserved: The approach used in this study is rooted in individual firm optimization and is estimated using data from industry aggregates. The criterion of internal closure of the model indicates that firms in an industry are taken as entities without a history. Firms in the same industry are viewed similarly, because they are assumed to have an identical demand curve and face the same cost curves. It is very common to study industries from this point of view of a representative firm. The cost function used in this study is assumed to be the cost function of representative firm.

In summary, the application of a dynamic factor demand model with ICT and non-ICT as quasi-fixed factors produces interesting and suggestive results. Additionally, the model lends itself to modifications for future research. For example, a future study employing another flexible functional form under rational expectations may provide more insight into the nature of the effect of ICT capital on the growth of TFP. Incorporating important intangible factors into the model and the relaxation of the separability between the quasi-fixed factors allows the investigation of the interaction between the quasi-fixed factors, as well as how the intangible factors affect the growth of TFP.

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초　록

전세계적으로 에너지 소비량은 지속적으로 증가하고 있다. 미국 EIA (2011)는 2035 년 전세계 에너지 소비량은 2011 년 대비 53% 증가할 것이라고 예측한 바 있다. 이러한 에너지 수요의 증가는 환경 및 에너지원의 가용성을 비롯하여 발전에 필요한 1 차에너지 수급에 부정적인 영향을 미칠 것이다. 특히 한국은 1 차에너지 수요의 전량을 수입에 의존하고 있으므로, 전기수요 증가는 에너지자립도 악화의 주요한 요인이 된다. 본 연구는 1980 년부터 2009 년까지 한국 30 개 산업 부분에 대하여 여러 생산요소가 에너지의 수요, 공급 및 시장에 미치는 영향을 정량적으로 분석하였다. 이 때, 정보통신기술(ICT)이 에너지 수요에 미치는 영향을 중점적으로 분석하였다. 특정 생산요소는 '조정비용(adjustment cost)' 없이는 단기에 투입량을 변화시키기 어려우므로, 분석에는 단기의 생산요소 투입에 대한 의사결정을 고려한 동태적요소수요모형(dynamic factor demand model)을 사용하였다. 본 학위논문의 목적은 첫째 한국 30 개 산업 부문의 생산성에 미치는 생산요소들의 구조를 연구하는 것이며, 특히 ICT 와 에너지 간 관계 및 ICT 가 총요소생산성(TFP)에 미치는 영향을 분석하는데 중점을 두었다. 도출된 각 산업부문의 생산성은 산업 정책의 설계, 공공자원의 배분, 생산성 증진 정책의 수립 등에 대한 중요한 참고자료로 사용될 수 있을 것이라 기대된다. 본 학위논문의 주요한 결과는 다음과 같이 요약된다.

첫째, ICT 자본과 비 ICT 자본은 노동과 에너지의 대체재로 나타났다. 둘째, ICT 자본재가 생산량 및 노동생산성 증가에 유의하게 기여하는 것으로 분석되었다. 셋째, 한국의 산업 부문에서는 높은 생산량 증가율과 규모의 경제가 관찰되었으며, 이들은 기술진보보다 총요소생산성 증가에 더 큰 영향을 미치는 것으로 분석되었다. 후속 연구에서는 각각의 에너지원이 생산에 미치는 영향을 분해하여 대체효과를 더욱 명확하게 도출할 것이며, ICT 의 도입이 에너지 절약에 직접적으로 미치는 영향을 분석할 예정이다.

주요어: 동태적요소수요; 패널자료분석; ICT 투자; 에너지 소비; 조정속도; 총요소생산성

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