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9 April 2014

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ABSTRACT: We examine productivity changes in Japan and South Korea during 1973–2006 and 1980–2009, respectively, in order to assess how investment in ICT 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 so-called adjustment costs, defined in terms of forgone output from current production. This study quantifies how ICT capital investment in Korea and Japan affects economic growth in general and industrial energy demand in particular. We find that ICT and non-ICT capital investment serve as substitutes for the inputs of labor and energy use. The results also demonstrate a decreasing trend for labor productivity as well as significant cost differences across industries in both countries.

Keywords: Dynamic factor demand; Panel data; ICT investment; Energy demand

JEL Classification Codes: C32;C33;Q41

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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 affects the environment and the availability of depletable energy sources of fuel, or 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 (the 2008 numbers are actual energy demand). This noticeable increase in energy consumption is due to the rapid economic development, industrialization, and population growth, especially in developing countries such as China and India with a vast population size. Strong economic development leads to an increase in the demand for energy in the industrial sector. The industrial sector consumes at least 37% of the total energy supply, which is relatively more energy intensive than any other major sectors including household, agriculture, and public services (Abdelaziz et al. 2011; Friedemann et al. 2010).

Table 1

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

Region	**2008**	**2015**	**2020**	**2025**	**2030**	**2035**	**Average Annual Percentage 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)

The steady increase in the demand for energy leads to increase in energy price. According to EIA (2011), the crude oil price will average 100 USD per barrel for the next twenty years, it will reach more than 200 USD per barrel in 2030. This increase in energy price according to the report is due to increase in the demand for oil and in the production cost. Industrial policy decision makers need to understand the importance of the energy in the industrial production structure, in order to assess and formulate the necessary energy conservation measures. Accordingly, it is essential to acquire knowledge about the energy demand and its characteristics such as the possible substitutability between energy and other factors of production (Dargay 1983; Koetse et al. 2008).

Unlike normal goods where supply response is applied to meet any possible 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 demand response program allows for the application of price variation/discrimination by type of consumer, location, season, and hours used per day, with the aim to reduce energy consumption. It improves the producer's and consumer's ability to optimize generation and energy use. Hence, better optimization improves energy use and efficiency, reduces energy generated by peak time reserve capacity at high cost, and also reduces energy consumption during peak time at high price (Heshmati 2013).

In the last twenty years the information and communications technology (ICT) has witnessed an advanced improvement, diffusion and use in all areas of production, distribution and consumption. It has spilled over into every industrial sector such as agriculture, water management, manufacturing, and most service sectors. It is considered as one of the most important driver of economic growth and effectiveness (Jaeger 2003; Friedemann et al. 2010). The important of the rapid substitution toward ICT for other factors is emphasized by Jorgenson and Stiroh (1999) due to induce in the rapid decline in ICT price. An average of more than 20% annual reduction in 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 ear (1992–1996), while the growth was reported to be 4% and 1% during the internet era (1996–2000). As reported by Laitner (2002) energy intensity was 4.4%, while it was only 0.8% for ICT sectors in 1996.

ICT investment has grown at a rapid rate in Japan since 1980 and in South Korea (Korea hereafter) since 1990. Nevertheless, according to Lu et al. (2007), Korea's CO_2 emissions from 1990 to 2002 were almost double those of Japan (42.4 million versus 24.2 million metric tons). This discrepancy suggests that the economic growth that occurred in parallel with ICT development has had no effect on energy supply and demand. However, few studies have thus far considered the link between ICT investment and energy consumption (Y. Cho et al. 2007). To that end, this study investigates whether ICT capital investment influences energy demand. In particular, we empirically examine the industrial productivity changes in Japan and Korea during 1973–2006 and 1980–2009, respectively, by applying and extending the dynamic factor demand model proposed by Nadiri and Prucha (2001).

The Korean government has implemented a number of industrial and technological policy initiatives to promote economic development (Khayyat and Heshmati 2014). In the 1980s, policymakers focused on growing foreign direct investment by concentrating on technology-based industries as a source for economic growth. Such a technology-led policy encouraged the private sector to invest in innovativeness and R&D as well as called for collaboration between ministries' R&D activities. In the 1990s, the Korean government continuously supported foreign direct investment in technology sectors and enhanced innovation capabilities in the private sector. Therefore, high-tech sectors were encouraged to internationalize. The globalization era in the 2000s was the last stage of the process of economic growth in Korea, where growth was mainly driven by technological progress and innovation. In general, Korea refocused its industrial strategy from being based on heavy industry to concentrating on technology-intensive sectors. Moreover, the government's intervention shifted from direct, sector-specific involvement to indirect, sector-neutral support. The aim of Korea's technology policy also evolved from the absorption of foreign technologies to the creation of new ones.

The remainder of this paper is organized as follows. Section 2 reviews the relevant literature and Section 3 discusses industrial demand as the input factors of production. A general theoretical model is specified in Section 4, the empirical model is introduced in section 5, where the first-order conditions for the optimal input path are derived. Finally, the discussion and concluding remarks are presented in Sections 6 and 7, respectively.

2. Methodology

Previous studies have found not only substitutability but also complementarity among factor inputs. Thompson (2006), for example, emphasized the degree and direction of energy use–capital substitutability by using Cobb–Douglas and translog production and cost functions to describe the substitution of capital and energy use through the derivation of cross-price elasticity.

By contrast, Kander and Schön (2007) found a high degree of complementarity between energy use and capital for Swedish industrial and manufacturing sectors during 1870–2000. By using a direct measure of technical efficiency, they investigated both short- and long-run energy use–capital relationships.

Arnberg and Bjorner (2007) applied translog and linear logit approximations in order to estimate factor demand models for capital, labor, and energy use based on Danish microdata for 1993–1997 and found labor to be substitutable with energy use and capital. Ma et al. (2008) applied a two-stage translog cost function to a panel dataset of 31 autonomous regions in China for 1995–2004 to measure the elasticities of substitution and found inter-factor substitutability (i.e., capital and labor are substitutes for energy use). In a literature survey on the elasticity of substitution, Koetse et al. (2008), using a meta-regression analysis of previous research results, found that energy use and capital are substitutes, with the degree of substitutability differing across regions and time periods.

Many scholars in recent years have studied the rapid diffusion of information and communication technology 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 equipment, which has led to substitution of ICT equipment for other forms of capital and labor. Accordingly, 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 et al. 2013). Earlier studies based on aggregated data suggested that ICT have no effect on productivity growth (Berndt and Morrison 1995; Jorgenson and Stiroh 1999; J. 2000). 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 witnessed. Their argument is that these disaggregated data enable the researchers 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 in rapid total factor productivity growth in the ICT industries (Siegel 1997; Stiroh 2002; Jorgenson et al. 2008; Oliner and Sichel 2000; Indjikian and Siegel 2005). Most of the studies in the literature mentioned above were based on the U.S. economy. With regard to non- US studies, most literature concluded that there is a significant positive relationship between ICT capital and economic growth (Biscourp et al. 2002; Hempell 2005; Matteucci et al. 2005). For the case of South Korea, several studies recommended this positive relationship between ICT and economic growth to be further re-assessed, especially from the increase of other industries' productivity as a result of using ICT in their production process (M. Kim and Park 2009; Khayyat 2013; Oh et al. 2014). The production structure is studied by S. Park (2014) covering 26 industries in 6 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.

ICT investment is found to depend on adjustment costs, so that it takes time for productivity gains to be realized (Ahn 1999; Amato and Amato 2000; Bessen 2002; Mun 2012). Another issue highlighted is the existence of ICT spillovers that have a significant impact on industries' productivity growth (Mun and Nadiri 2002; Chun and Nadiri 2008). 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).

The ICT capital investment and energy use relationship has also been extensively studied (Sadorsky 2012; Khayyat and Heshmati 2014; Khayyat 2013). The two oil price shocks in the 1970s redirected scholarly interest toward ways in which to reduce energy consumption by increasing ICT usage (Walker 1985, 1986). Recent studies have further shown that ICT and energy use are substitutes. Y. Cho et al. (2007) studied the impact of ICT investment and energy price on electricity consumption in Korea and found that ICT reduces electricity demand in certain manufacturing sectors. According to a recent study conducted by J. Kim and Heo (2014), ICT capital substitutes electricity and fuel in US and UK manufacturing. Although ICT capital, electricity, and fuel has substitution effects between each other in Korean manufacturing, ICT capital is unlikely to decrease the demands for electricity and fuel when considering their relative price changes

The literature review presented in this section suggests that different specifications are used to model production, cost, and energy demand, or a combination thereof, depending on whether the objective is cost minimization or output maximization. While different studies utilize data on diverse countries, regions, and industrial sectors, the findings tend to indicate substitution between capital (ICT and non-ICT), and energy use, although complementarity between energy use and capital is also frequently observed. The degree of substitutability and complementarity differ significantly according to the data dimensions and unit characteristics.

3. Industrial Demand for Factor Inputs

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. The 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, in which it accounted for more than twice of the world average energy consumption. Although an increase in the use of renewable energy is expected, it will not contribute to 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 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 (Lee et al. 2012). Different energy conservation programs have been promoted. 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 vast 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 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. Within the frame of the energy plan, the Korean industrial sector will have to reduce its energy consumption as minimum as 44% (IEA 2011, 2009). The second national energy plan issued in January 2014 has mainly changed the policy direction from protecting the energy industry to require a paradigm shift in the policy direction. The paradigm shift includes changes in the policy goals, in the market system, in the international relation, and emphasizing on the Technology development that emerges as the core element of competitiveness. The energy policy to pursue a new goal of "sustainable development" to take into consideration economic growth, environment, and energy security factors. One of the essential policy direction is that energy prices and demand and supply will be led by market system rather than government's intervention as it was the case. Another vital change in the policy is that with emphasizing on the global market competition, the competitiveness of the energy industry will intensively depend 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 to have the motivation to innovate and develop advanced applied technologies. Rather, the government was taking the initiative in developing common-basic technologies that fit with domestic demand conditions2.

[2] The detailed national energy plan can be found in 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

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 sector, while the largest share of fuel mix in the industrial sector is represented by liquid fuel consumption for feedstock use (IEA 2011). Figure 1 shows the development of energy use in the Korean industrial sectors for the years 1980-2010. The figures are based on the aggregate level of energy used in the industrial sector.

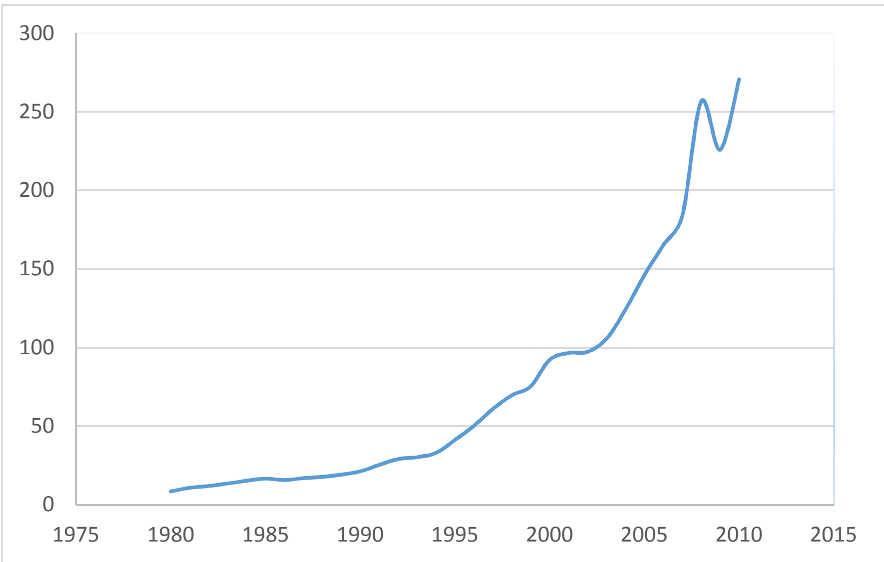

***Figure 1**:* Total Industry Energy Consumption in South Korea (in millions of USD), 1980–2010

The estimated models of industrial demand for the input factors of production can be classified into two main groups: static and dynamic. Pindyck and Rotemberg (1983) and Morana (2007) argued that a static model implicitly assumes that all factor inputs adjust instantaneously to their long-run equilibrium values and therefore cannot depict real economic activity where the adjustment process can only be gradual. Dynamic factor demand models were thus introduced to address the problems of neglected dynamics, such as parameter instability and serially correlated residuals. The model used in this study is a third-generation dynamic factor demand model. According to Morana (2007), the key feature of factor demand models is the introduction of adjustment costs for quasi-fixed inputs. Mun (2002) argued that the traditional neoclassical model of investment assumes the existence of internal adjustment costs from the expanding physical capital stock. In the 1990s, for example, ICT investment showed high growth in the United Kingdom and the United States, thus incurring considerable adjustment costs (Groth 2005).

The present study expands the dynamic factor demand model proposed by (Nadiri and Prucha 1986, 1990, 1996, 1999, 2001) by using materials, energy use, and labor as variable inputs and distinguishing between ICT and non-ICT capital as quasi-fixed inputs. According to the framework developed by these authors, firms maximize the present value of their future profit streams by choosing their levels of output and determining the optimal input levels of energy use, ICT capital, and other input factors of production accordingly. In the short run, firms use both quasi-fixed inputs (ICT and non-ICT capital) and variable inputs (labor, materials, and energy use). Variable inputs fully adjust from one period to the next, while quasi-fixed inputs are only 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 the short- and long-run price elasticities, provides 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 tend to economize on energy use. Hence, the reaction to a potentially permanent rise in energy prices may be less in the immediate future than it is in the long run. An industry's technological features are captured by economies-of-scale measures and degrees of substitutability between the different input factors of production.

4. Theoretical Framework

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

(1) $$Y_{it} = F(V_{it}, X_{it-1}, \Delta X_{it}, T_{it})$$

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 that represents the internalization of the adjustment costs in 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[3]. A change in the levels of the quasi-fixed factors will result in incurring adjustment costs because of the resource allocation require to change the input stock rather than product level.

The duality principle in production theory indicates that given a production function, under the appropriate regularity conditions, it is possible to derive the corresponding firm's total

[3] The function F is assumed to be twice continuously differentiable, while $\partial F/\partial v > 0$, $\partial F/\partial x_{t-1} > 0$, and $\partial F/\partial \Delta X < 0$. In addition, F is strictly concave in all arguments, except, possibly, for the technology index.

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, that is it should be a concave, non-decreasing, and 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 as $\hat{p}_{i,t}^{V_s} (s = 1, 2, \ldots, m)$ and $\hat{q}_{i,t}^{X_d} (d = 1,2, \ldots, n)$, respectively. All prices are normalized to the price of the first variable factor—this procedure has been found convenient. These normalized prices are denoted as $p_{i,t}^{V_j} = \hat{p}_{i,t}^{V_s} / \hat{p}_{i,t}^{V_1}$ and $q_{i,t}^{X_j} = \hat{q}_{i,t}^{X_d} / \hat{p}_{i,t}^{V_1}$, $(j = 1,2, \ldots, m)$. The normalized restricted cost function is then defined as follows:

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

Where $\hat{V}_{jt}$ denotes the cost-minimizing variable inputs required to produce output $Y_{i,t}$ conditional on $Xi_{,t-1}$ and $\Delta X_{i,t}$ and the normalized restricted cost function *G(.)* is assumed to be convex in $Xi_{,t-1}$ and $Xi_{,t}$, and concave in $p_{i,t}^{V}$ (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, meaning that short- and long-run costs will differ. The firm's cost in period *t* is specified as follows:

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

Where $\Omega_{i,t}$is a vector composed of $\mathrm{p}^{V_j}_{i,t}, \mathrm{q}^{X_j}_{i,t}, Y_{i,t}$ and $T_{i,t}$. The real investment of the *h^th^* quasi-fixed input is defined as follows:

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

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 according to the planning horizon into finite and infinite planning horizon. For the infinite planning horizon, the firm's objective function in period τ is defined as follows:

(6) $\sum_{\tau=0}^{\infty} C(\mathrm{X}_{\tau}, \mathrm{X}_{\tau-1,}, \mathrm{E}\Omega_{\tau})(1 + \mathrm{r})^{-\tau}$

where E denotes the expectations operator conditional on information available at the beginning of period τ and *r* is the real interest rate. The firm in each period τ derives an optimal plan for the quasi-fixed inputs for period $\tau, \tau + 1, \ldots$ such that equation (6) is minimized subject to the initial stocks $\mathrm{X}_{\tau-1,}$, and then chooses its quasi-fixed inputs in period τ according to this plan. In each period the firm 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 are 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 horizon are assumed to be determined endogenously subject to the assumption of static expectations, the optimal plans converges rapidly to those of the infinite planning horizon model as the planning horizon extends (Nadiri and Prucha 1990). Accordingly, this study applies the optimal plans for the infinite planning horizon.

5. Empirical Model

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 static expectations:

$$(7)\quad \min_{K_{t+\tau}, ICT_{t+\tau}} \sum_{\tau=1}^{\infty}[G(p_{i,t}^{L}, p_{i,t}^{E}, K_{i,t+\tau-1}, ICT_{i,t+\tau-1}, \Delta K_{i,t+\tau}, \Delta ICT_{i,t+\tau}, h(Y_{i,t+\tau}), T_{i,t+\tau}) + p_{i,t}^{K} I_{i,t+\tau,} + p_{i,t}^{ICT} H_{i,t+\tau}](1 + r_{i,t})^{-\tau}$$

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 the prices for energy, labor, ICT capital, and non-ICT capital normalized by the price of materials, respectively, and *H* and *I* are the real investment in ICT 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.

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

(8) $G\left(p_{i,t}^L, p_{i,t}^E, K_{i,t-1}, ICT_{i,t-1}, \Delta K_{i,t}, \Delta ICT_{i,t}, Y_{i,t}, T_{i,t}\right) = M_{i,t} + p_{i,t}^L L_{i,t} + p_{i,t}^E E_{i,t} =$

$\Big[a_0 + a_l p_{i,t}^L + a_e p_{i,t}^E + a_T T_{i,t} + a_{Tl} T_{i,t} p_{i,t}^L + a_{Te} T_{i,t} p_{i,t}^E + a_{el} p_{i,t}^L p_{i,t}^E + \frac{1}{2} a_{ll} \left(p_{i,t}^L\right)^2 +$

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

$\frac{1}{2} a_{I\dot{C}TI\dot{C}T} \Delta \mathrm{ICT}_{i,t}^2\Big] \frac{1}{Y_{i,t}} + a_{lK} p_{i,t}^L K_{i,t-1} + a_{lICT} p_{i,t}^L ICT_{i,t-1} + a_{eK} p_{i,t}^E K_{i,t-1} + a_{eICT} p_{i,t}^E ICT_{i,t-1} +$

$a_{TK} K_{i,t-1} T_{i,t} + a_{TICT} ICT_{i,t-1} T_{i,t}$

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 at the steady state of the 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) $a_{\dot{K}} = a_{I\dot{C}T} = a_{l\dot{K}} = a_{lI\dot{C}T} = a_{K\dot{K}} = a_{ICTI\dot{C}T} = a_{\dot{K}I\dot{C}T} = a_{ICT\dot{K}} = a_{T\dot{K}} = a_{TI\dot{C}T} = 0$

where a dot over a variable represents the growth rate of 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, the separability of the quasi-fixed input implies that $\mathrm{a_{KICT}} = \mathrm{a_{\dot{K}I\dot{C}T}}$. Moreover, the convexity and concavity conditions of the normalized restricted cost function under the separability assumption imply that $\mathrm{a_{KK}}, \mathrm{a_{ICTICT}}, \mathrm{a_{\dot{K}\dot{K}}}, \mathrm{a_{I\dot{C}TI\dot{C}T}} > 0$, and $\mathrm{a_{ll}}, \mathrm{a_{ee}} < 0$. 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) $-a_{\dot{K}\dot{K}}K_{i,t+\tau+1} + [a_{\dot{K}\dot{K}} + (2 + r_{i,t})a_{\dot{K}\dot{K}}]K_{i,t+\tau} - (1 + r_{i,t})a_{\dot{K}\dot{K}}K_{i,t+\tau-1} = -\Big((1 - \delta)p^K_{i,t} + a_K + a_{lK}p^L_{i,t} + a_{eK}p^E_{i,t} + a_{TK}T_{i,t}\Big)h(Y_{i,t})$

(12) $-a_{I\dot{C}TI\dot{C}T}ICT_{i,t+\tau+1} + [a_{I\dot{C}TI\dot{C}T} + (2 + r_{i,t})a_{I\dot{C}TI\dot{C}T}]ICT_{i,t+\tau} - (1 + r_{i,t})a_{I\dot{C}TI\dot{C}T}ICT_{i,t+\tau-1} = -\Big((1 - \mu)p^{ICT}_{i,t} + a_{ICT} + a_{lICT}p^L_{i,t} + a_{eICT}p^E_{i,t} + a_{TICT}T_{i,t}\Big)h(Y_{i,t})$

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

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

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

The accelerator equations described by Nadiri and Prucha (1990) serve as a solution that corresponds 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) $m_{KK} = -\frac{1}{2}\left[\left(r_{i,t} + a_{KK}/a_{\dot{K}\dot{K}}\right) - \left(\left(r_{i,t} + a_{KK}/a_{\dot{K}\dot{K}}\right)^2 + 4\,a_{KK}/a_{\dot{K}\dot{K}}\right)^{1/2}\right]$

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

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

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

where a star indicates the optimal or target levels of the quasi-fixed inputs.

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

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

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

From Shephard's lemma, the variable input demand equations for labor *L*, energy use *E*, and materials *M* can be obtained as follows:

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

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

From $G(.) = M_{i,t} + p^L_{i,t} L_{i,t} + p^E_{i,t} E_{i,t}$, the demand equation for variable materials is described as follows:

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

$a_{el} p^L_{i,t} p^E_{i,t}\Big] Y_{i,t} + a_K K_{i,t-1} + a_{ICT} ICT_{i,t-1} + \Big[\frac{1}{2} a_{KK} K^2_{i,t-1} + \frac{1}{2} a_{ICTICT} ICT^2_{i,t-1} + \frac{1}{2} a_{\dot{K}\dot{K}} \Delta K^2_{i,t} +$

$\frac{1}{2} a_{I\dot{C}TI\dot{C}T} \Delta ICT^2_{i,t}\Big] \frac{1}{Y_{i,t}} + a_{TK} K_{i,t-1} T_{i,t} + a_{TICT} ICT_{i,t-1} T_{i,t}$

The entire system of equations to be estimated consists of the two quasi-fixed input and three variable input equations (14) to (18).). 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 normalized restricted cost function via shepherd's lemma. 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 methods. We thus estimate the model parameters by using the full-information maximum likelihood (FIML) method with the SAS 9.3 application package.

6. Results and Discussion

6.1 Data Sources and Construction of the Variables

The data used in this study are obtained from different sources, mainly the harmonized Asia-KLEMS growth and productivity accounts database released in June 2012 for Korea, and the

EUKELMS growth accounting database for Japan. These two 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 use, materials, and ICT capital inputs. The greatest advantage of this dataset is that it provides data series for almost all organized industrial sectors (O'Mahony and Timmer 2009; Pyo et al. 2012). Labor is measured as total hours worked. Energy use is defined as the aggregate of energy mining, oil refining, and electricity and gas products. Real non-ICT capital stock (converted into 2005 prices) is taken from the Korea Industrial Productivity Database 2012. The macroeconomic variables are taken from the Bank of Korea's Economic Statistics System[4].

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 rate (assumed to be 30 percent). The macroeconomic variables are taken from the Bank of Japan database[5]. The Japanese part of the EUKLEMS database includes 72 industries, but only those matching the corresponding Korean industries are used for the comparative analysis. For the definition of the variables used, see Table A.1 in appendix A. In addition to the measures mentioned above, this study includes variables for export/import-oriented industry, industry size, R&D intensity, and labor skills (high, medium, and low categories) for the 30 main industrial sectors in Korea and Japan, see table A.2 in appendix A.

6.2 Empirical model

The system equations include dummy variables in order to capture industry-specific effects because the heterogeneity across industries cannot be explained by the production structure

[4] These data are publicly available at http://ecos.bok.or.kr/EIndex_en.jsp/.
[5] These data are publicly available at http://www.stat-search.boj.or.jp/index_en.html/.

alone[6]. The variance-covariance estimator used for the full-information maximum likelihood (FIML) method is from a generalized least squares estimator. Therefore, the generalized least squares approximation to the Hessian is used in the minimization procedure.

The sample periods for each of the studied countries were divided into three sub-periods[7]: 1980–1989, 1990–1999, and 2000–2009 for Korea and 1974–1984, 1985–1995, and 1996–2006 for Japan. In addition, both samples were divided into knowledge-based and non-knowledge-based industries. The parameter estimates reported in Table B.1 and Table B.2 in Appendix B for Korea and Japan, respectively, are in general statistically highly significant and satisfy the conditions of the convexity of the normalized restricted cost function in ICT and non-ICT capital, and the concavity in variable input prices. Further, the parameter estimates $a_{KK}, a_{\dot{K}\dot{K}}, a_{ICTICT},$ and $a_{IC\dot{T}IC\dot{T}}$ are positive, while a_{ll} and a_{ee} are negative. The hypothesis of the absence of adjustment costs for the quasi-fixed inputs of ICT and non-ICT capital, $a_{\dot{K}\dot{K}} = 0$ and $a_{IC\dot{T}IC\dot{T}} = 0$, is thus rejected. Hence, we deem the static equilibrium model to be unsuitable for describing the technology and structure of the factor demand of Korean and Japanese industries.

Demand for variable inputs depends negatively on their own normalized prices. The negative signs of the quasi-fixed inputs of ICT and non-ICT capital in the labor and energy use demand functions indicate that both forms of investment are substitutes for labor and energy use. In addition, the positive sign of the technology index parameter in the labor demand function implies decreasing labor productivity. Moreover, the significant coefficients for the industry-specific dummy variables imply that significant differences exist in the cost structure across

[6] We use the fixed effects approach owing to the presence of panel data

[7] The aim here is to reflect the structural changes in the Korean economy because of the implementation of the country's economic development plan described in Section 1.

industries[8]. Finally, because the parameter estimates are difficult to interpret, the various implied characteristics for the estimated factor demand systems are presented in the following estimates.

6.2. Adjustment speed

The estimated adjustment speed coefficients for ICT and non-ICT capital are reported in Table 2 and Table 3 for Korea and Japan, respectively. The optimal paths for these quasi-fixed inputs are described by the flexible accelerator equations, or so-called partial adjustment coefficients, in equations. (13.3) and (13.4). The adjustment coefficients explain the size of the gap between the initial stock and respective long-run optimal values, which alter over time in response to changes in those variables exogenous to the firm's input decisions (Morrison and Berndt 1981; Nadiri and Prucha 1990). Further, the stock of quasi-fixed inputs moves slowly (quickly) toward the optimal value as the adjustment speed coefficient approaches zero (one).

Table 2

Korea's adjustment speed coefficients

	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

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

Table 3

Japan's adjustment speed coefficients

	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 Korea, the coefficients of ICT and non-ICT capital for 1980–1989 are 0.084 and 0.131, respectively. This finding implies that in 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 a year. Thus, the overall adjustment speed in 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 non-ICT capital was slower than that for 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 of the ICT adjustment speed is due to technological diffusion and the strengthening of technology linkages across industries since the 1990s. Moreover, high investment in ICT is partly due to the rapid decline in ICT capital prices, which allowed for substituting between different types of capital goods. Further, ICT capital investment might be driven by the perceived benefits that industries expect from ICT such as higher efficiency (Pilat and Lee 2001).

For Japan, the adjustment speed for ICT capital was slower than that for non-ICT capital during the first and 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 et al. (2009), who argued that ICT investment has become more feasible in Japan since the late 1990s given the contribution of IT to the country's GDP growth.

For both countries, the ICT adjustment speed was faster in traditional industries than it was in 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.

6.3. Elasticities

The short- and long-run price and output elasticities of factor demand are reported in Appendix B: Tables B.3 and B.4 for Korea and Tables B.5 and B.6 for Japan. The short-run elasticities of the variable inputs are defined when the quasi-fixed inputs are fixed, while the long-run elasticities occur when the inputs have adjusted fully to their steady-state levels. 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 are both less than one, which means that their demand is inelastic. This demand behavior can be explained through their short- and long-run elasticities. In the short-run, the behavioral specifications as well as policy variables (e.g., 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 degree of availability of new technologies as well as substitutability or complementarity become applicable as the size and technological characteristics of the capital stock vary (Hartman 1979).

For both countries, ICT capital and labor are substitutes in all periods. In particular, they are perfect substitutes in the second and third sub-periods in Japan. Moreover, ICT diffusion caused a decrease in labor demand in all periods, indicating the existence of ICT and labor substitution effects. These results support the finding of G. Park and Park (2003) that Korean industries increasingly deploy ICT in order to reduce the use of labor, leading to the emergence of skills-biased technological change. In other words, the use of ICT, although replacing low-skilled labor, is creating high-skilled complex jobs. As explained by Kanamori and Motohashi (2007), the contribution of the labor force to production and GDP growth in Japan has declined because of the declining birthrate, possibly leading to a negative growth rate in the long-run. As a result, the increase in total factor productivity and emphasis on ICT have become the most important policy initiatives for the Japanese government. In particular, promoting ICT investment and accelerating its effective use are vital for enhancing competitiveness among Japanese industries and for long-run economic growth. This trend also supports the finding that the elasticity of labor with respect to ICT capital in traditional industries is identical to that in knowledge-based industries in Japan but higher in Korea. Finally, we find that firms that incur a high amount of R&D expenditure have more high-skilled labor, while traditional industries that aggressively adopt ICT tend to reduce demand for low-skilled labor.

In 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 first and third sub-periods, ICT complements energy use and labor (negatively in relation to time), implying that labor provides an opportunity to substitute for energy use, whereas employment does not influence energy consumption. The positive output elasticity of energy, which is less than one in both countries, suggests that economic growth leads to higher energy use, but also at a higher degree of energy efficiency. Therefore, although economic growth can improve the per-unit productivity of energy use, it increases both total energy use and CO_2 emissions.

Over time, no systematic pattern was observed in the trend of energy price elasticity implying that the economic growth–energy demand relationship has become more feasible after industrialization (Kamerschen and Porter 2004). The rapid development of production capacity in Korean industries over time has expanded these industries as well as urbanization and economic growth (Lee et al. 2012). As a result, changes in energy price have little effect on energy demand over time.

The industrialization process in Korea has transformed its agriculture-dominated economy into a services-based one that has an annual GDP growth of 2.9% (W. G. Cho et al. 2004). However, the high growth rates of 4–5% observed during the post-war industrialization period increased energy demand significantly. The shift of industry focus from labor-intensive to more capital- and energy-intensive production might explain this finding, while urbanization has also played a role by expanding services, food delivery, and infrastructural development and maintenance (Liu 2009).

The energy demand in Japan started to decline since 1982 after its peak in 1979. The energy conservation policy was stimulated because of the oil crises. Moreover the Japanese industrial policy shifted from high energy intensity to low energy intensity industries. However, the energy demand started to rise again in 1983 but with lower growth rate compared with the past trend(Uchiyama 2002).

Materials elasticity accounts for the largest proportion of elasticity in both Korea and Japan. Technological progress leads to greater materials efficiency in the production process by recycling waste and reusing materials. Technologically advanced firms are able to change their manufacturing processes over time by decreasing their use of expensive materials and redistributing resources. Moreover, the tariff exemption policy for imports of raw materials and investment goods, implemented by the Korean government after the 1980s as part of its economic development plan, and import liberalization in general have increased the supply of low-cost materials (Lee et al. 2012).

7. Conclusion

This study quantified how ICT investment in Korea and Japan affects economic growth in general and industrial energy demand in particular, by using a dynamic factor demand model. The presented results showed that increasing ICT capital investment can improve both the global competitiveness and the productivity of Korean and Japanese industries. The substitution effect of ICT capital is manifested in energy-related activities, such as the shift from energy-intensive industries (e.g., iron & steel and chemicals) to electronic-based high-tech activities that are typically less energy-intensive. According to the elasticities calculated herein, ICT capital substitutes energy use. However, the magnitude of the ICT capital substitution effect determines whether such a capital investment decreases energy demand.

Given these findings, future studies might aim to decompose aggregated energy consumption figures into different energy types in order to evaluate their individual effects on industrial production and specify their substitution effects more accurately. Researchers might also consider the direct effects of ICT on energy conservation.

Further, the approach used in this study is rooted in individual industry optimization estimated from aggregated industry data. For instance, our model assumes that energy demand for all firms in the same industry is the same (i.e., they have identical demand curves and face similar cost curves). While it is common to study industries from the point of view of a representative firm, it should be noted that the cost function used in this study is assumed to be that of a representative firm in the industry.

Moreover, the model lends itself to modifications in future research. For example, studies that use more flexible functional forms (e.g., a translog function) under rational expectations may provide more insights into how ICT capital influences energy demand. Finally, incorporating important intangible input factors into the model and relaxing the separability between the quasi-fixed factors may also allow us to understand the interaction between these factors and examine more in depth their effects.

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Appendix A

Data Sources and Construction of the Variables

Table A.1

Definition of Variables

Variable	Description	Source
Sector	32 industries are selected	Asia KLEMS Growth and Productivity Database for Korea and EUKLEMS 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 worked, 2005 reference	Same as above
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 EUKLEMS 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 A.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 and Timmer 2009);
CDR	Non-Capital Depreciation Rate: The Average Depreciation Rate of Machinery, Transport Equipment, and Non-Residential Structure	Asia KLEMS Growth and Productivity Database for Korea and EUKLEMS Growth and Productivity Database for Japan
Ip_Lab	Price Index of Labor	Calculated based on LAP_QPH
I	ICT Capital Stock (in 2005 Prices), i.e . (CAPIT * Kstock)	The share is taken from the 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)

Table A. 3

*Industry Sectors Classification**

ID	Description	Technology Level	Export Market Orientation	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

*The letters H, M, and L refer to High, Medium, and Low, respectively.

Table A. 4

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 A. 5
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

Appendix B

Parameter Estimates

Table B.1

Korea's non-linear FIML estimates-dynamic factor demand, 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**
akk	0.073*** (0.011)	6.390	0.085*** (0.007)	11.880	0.066*** (0.009)	7.440	0.039*** (0.006)	6.850	0.094*** (0.006)	14.640
akoko	2.522*** (0.427)	5.910	1.506*** (0.153)	9.820	1.848*** (0.242)	7.640	1.382*** (0.155)	8.920	1.365*** (0.102)	13.370
ak	-0.142*** (0.035)	-4.030	-0.169*** (0.014)	-11.880	-0.078*** (0.11)	-7.120	-0.163*** (0.018)	-9.130	-0.101*** (0.011)	-9.010
alk	-0.048*** (0.016)	-3.080	-0.037*** (0.008)	-4.880	0.000 (0.008)	-0.040	-0.016** (0.007)	-2.110	-0.021*** (0.004)	-5.510
aek	-0.040*** (0.017)	-2.430	-0.055*** (0.007)	-7.870	-0.034*** (0.004)	-9.160	-0.046*** (0.005)	-10.180	-0.026*** (0.003)	-8.510
atk	-0.001 (0.003)	-0.320	0.002** (0.001)	1.700	-0.002** (0.001)	-2.530	0.004*** (0.0001)	8.220	-0.002*** (0.000)	-5.410
aii	0.201*** (0.025)	7.930	0.169*** (0.018)	9.650	0.105*** (0.007)	14.750	0.119*** (0.011)	10.800	0.143*** (0.007)	21.340

aioio	15.300*** (0.066)	7.400	0.826*** (0.069)	11.950	1.283*** (0.125)	10.250	2.033*** (0.225)	9.020	0.963*** (0.048)	20.010
ai	-0.225*** (0.058)	-3.860	-0.259*** (0.021)	-12.430	-0.123*** (0.011)	-10.970	-0.292*** (0.030)	-9.610	-0.118*** (0.010)	-12.000
ali	-0.094*** (0.028)	-3.350	-0.083*** (0.015)	-5.620	-0.013 (0.011)	-1.240	-0.033** (0.020)	-1.670	-0.051*** (0.006)	-8.480
aei	-0.059** (0.031)	-1.920	-0.085*** (0.009)	-9.700	-0.059*** (0.005)	-12.090	-0.071*** (0.011)	-6.300	-0.056*** (0.004)	-13.570
ati	-0.008 (0.005)	-1.470	0.002* (0.002)	0.860	-0.007*** (0.001)	-5.090	0.005*** (0.001)	4.430	-0.005*** (0.001)	-9.220
al	0.993*** (0.195)	5.100	1.423*** (0.219)	6.510	0.735*** (0.262)	2.810	1.269*** (0.201)	3.160	0.226 (0.256)	0.880
all	-0.361*** (0.040)	-9.140	-0.036*** (0.010)	-3.580	-0.023* (0.014)	-1.620	-0.018 (0.016)	-1.130	-0.008* (0.006)	-1.470
ael	0.204*** (0.029)	6.990	0.031*** (0.008)	4.070	0.005 (0.007)	0.700	0.009 (0.009)	0.990	0.005* (0.003)	1.630
alt	0.003 (0.024)	0.140	-0.045 (0.030)	-1.490	0.043 (0.029)	1.510	-0.015 (0.016)	-0.920	0.037*** (0.009)	4.010
ae	0.922*** (0.109)	8.450	0.966*** (0.057)	16.960	0.917*** (0.058)	15.890	1.338*** (0.154)	8.690	0.744*** (0.037)	20.220
aee	-0.120*** (0.036)	-3.350	-0.014** (0.006)	-2.160	0.012*** (0.004)	3.080	-0.015** (0.007)	-2.020	0.000 (0.002)	-0.170

aet	-0.023** (0.011)	-2.100	0.008* (0.007)	1.190	0.003 (0.006)	0.490	-0.021*** (0.005)	-3.850	0.006*** (0.001)	4.330
a0	1.067*** (0.241)	4.420	1.122*** (0.063)	17.770	0.901*** (0.060)	15.080	1.505*** (0.161)	9.340	0.758*** (0.043)	17.440
at	-0.006 (0.030)	-0.190	0.007 (0.008)	0.830	0.008 (0.006)	1.260	-0.027*** (0.006)	-4.810	0.012*** (0.002)	7.170
Log Likelihood		1054	634.01		470.81		155.9		685.1	

Table B.2

Japan's non-linear FIML estimates-dynamic factor demand, 30 sectors (1973–2006)

	1973–1982		1983–1999		2000–2009		Knowledge-Based		Non-Knowledge-Based	
Parameter	**Estimate**	***t*-value**	**Estimate**	***t*-value**	**Estimate**	***t*-value**	**Estimate**	***t*-value**	**Estimate**	***t*-value**
akk	0.128*** (0.018)	6.990	0.175*** (0.012)	14.700	0.068*** (0.011)	6.280	0.122*** (0.013)	9.080	0.128*** (0.010)	13.510
akoko	1.372*** (0.192)	7.150	0.736*** (0.089)	8.240	3.082*** (0.497)	6.200	1.383*** (0.252)	5.490	1.991*** (0.204)	9.780
ak	-0.105*** (0.022)	-4.720	-0.162*** (0.013)	-12.630	-0.059*** (0.015)	-3.930	-0.134*** (0.020)	-6.750	-0.146*** (0.012)	-12.310
alk	-0.161*** (0.018)	-8.920	-0.119*** (0.016)	-7.460	-0.095*** (0.013)	-7.580	-0.131*** (0.018)	-7.400	-0.097*** (0.012)	-8.130
aek	-0.019* (0.010)	-1.960	-0.024*** (0.007)	-3.300	-0.015* (0.009)	-1.640	-0.030*** (0.010)	-3.000	-0.023*** (0.006)	-3.690
atk	0.000 (0.001)	0.130	-0.003*** (0.001)	-3.950	-0.001*** (0.000)	-2.760	0.002*** (0.000)	4.200	0.001** (0.000)	1.800
aii	0.404*** (0.025)	16.340	0.116*** (0.010)	11.090	0.032*** (0.002)	14.940	0.052*** (0.006)	8.780	0.092*** (0.005)	20.420
aioio	4.955*** (0.362)	13.700	0.883*** (0.059)	14.870	0.041*** (0.005)	8.760	0.136*** (0.019)	7.010	0.070*** (0.004)	16.030
ai	-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)	
ali	-0.162***	-2.750	-0.198***	-9.930	-0.171***	-9.980	-0.271***		-0.236***	
	(0.059)		(0.020)		(0.017)		(0.029)	-9.410	(0.014)	-17.330
aei	0.047***	2.100	-0.020**	-2.200	0.016**	1.990	0.081***		0.024***	
	(0.022)		(0.009)		(0.008)		(0.010)	8.330	(0.007)	3.580
ati	0.004***	3.240	-0.002***	-5.030	-0.003***	-3.800	0.002**		-0.003***	
	(0.001)		(0.000)		(0.001)		(0.001)	2.380	(0.000)	-6.380
al	1.050***	19.570	1.144***	33.880	1.258***	30.820	0.959***		0.835***	
	(0.054)		(0.034)		(0.041)		(0.097)	9.950	(0.033)	25.610
all	-0.067***	-2.810	0.015***	0.450	0.124***	4.250	0.152***		-0.115***	
	(0.024)		(0.034)		(0.029)		(0.051)	2.960	(0.018)	-6.490
ael	0.040***	1.740	-0.008	-0.490	-0.079***	-4.430	-0.103***		0.074***	
	(0.023)		(0.016)		(0.018)		(0.028)	-3.690	(0.012)	6.250
alt	0.016***	2.780	0.021***	5.160	0.003	0.510	0.012***		0.020***	
	(0.006)		(0.004)		(0.006)		(0.004)	3.100	(0.001)	13.720
ae	0.866***	12.770	1.137***	52.510	0.843***	16.790	1.555***		1.055***	
	(0.068)		(0.022)				(0.060)	25.990	(0.025)	42.930
aee	-0.030***	-1.780	0.001	0.110	0.035***	2.840	0.029*		-0.056***	
	(0.017)		(0.008)		(0.012)		(0.019)	1.520	(0.008)	-6.890
aet	0.033***	3.830	-0.022***	-6.710	-0.008	-1.510	-0.032***		-0.009***	
	(0.009)		(0.003)		(0.006)		(0.002)	-13.330	(0.001)	-10.160
a0	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)	
	0.031***		-0.018***		-0.003		-0.027***		-0.006***	
at		3.370		-5.020		-0.520				
	(0.009)		(0.004)		(0.005)		(0.003)	-10.410	(0.001)	-5.070
Log Likelihood		1848	2211		1070		535		1974	

Table B.3

Korea's short- and long-run price and output elasticities for the studied three decades

	Short-Run Elasticities														
	1980–1989					**1990–1999**					**2000–2009**				
	L	***E***	***M***	***K***	***ICT***	***L***	***E***	***M***	***K***	***ICT***	***L***	***E***	***M***	***K***	***ICT***
PL	-0.22	0.24	0.29	0	0	-0.03	0.03	0.77	0	0	-0.01	0.01	0.34	0	0
PE	0.24	-0.09	0.54	0	0	0.03	-0.01	0.43	0	0	0.01	-0.02	0.49	0	0
PM	0.29	0.54	-0.03	0	0	0.78	0.43	-0.94	0	0	0.34	0.49	-0.13	0	0
CK	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CICT	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
Q	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														
PL	-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
PE	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
PM	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
CK	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
CICT	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

Q	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 B.4

Korea's short- and long-run price and output elasticities of knowledge- and non-knowledge-based industries

	Short-Run Elasticities									
	Knowledge-Based Industries					**Non-Knowledge-Based Industries**				
	L	***E***	***M***	***K***	***ICT***	***L***	***E***	***M***	***K***	***ICT***
PL	-0.01	0.001	0.73	0	0	-0.01	0.01	-0.05	0	0
PE	0.001	-0.02	0.84	0	0	0.01	-0.00	0.39	0	0
PM	0.73	0.84	-0.96	0	0	-0.05	0.39	-0.01	0	0
CK	0	0	0	0	0	0	0	0	0	0
CICT	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
Q	0.57	0.81	0.12	0	0	0.58	0.59	0.26	0	0
	Long-Run Elasticities									
PL	-0.03	-0.04	1.5	0.08	0.20	-0.03	-0.02	-0.06	0.04	0.27
PE	-0.04	-0.12	-0.01	0.10	0.42	-0.02	-0.03	0.81	0.05	0.38
PM	1.5	-0.01	-0.96	0.01	-0.07	-0.06	0.81	-0.49	-0.16	-0.05
CK	0.08	0.10	0.01	-0.04	0	0.04	0.05	-0.16	-0.10	0
CICT	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
Q	0.60	0.93	0.54	1.00	1.00	0.68	0.60	0.41	1.00	1.00

Table B.5

Japan's short- and long-run price and output elasticities for the three studied decades

	1974–1984					1985–1995					1996–2006				
	L	***E***	***M***	***K***	***ICT***	***L***	***E***	***M***	***K***	***ICT***	***L***	***E***	***M***	***K***	***ICT***
Short-Run Elasticities															
PL	-0.17	-0.06	0.40	0	0	-0.01	-0.01	0.41	0	0	-0.14	-0.11	0.65	0	0
PE	-0.06	-0.11	0.47	0	0	-0.01	-0.001	0.64	0	0	-0.11	-0.05	0.69	0	0
PM	0.40	0.47	-0.46	0	0	0.41	0.64	-0.99	0	0	0.65	0.69	-1.00	0	0
CK	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CICT	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
Q	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															
PL	-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
PE	-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
PM	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
CK	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
CICT	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

Q	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 B.6

Japan's short- and long-run price and output elasticities of knowledge- and non-knowledge-based industries

	Short-Run Elasticities									
	Knowledge-Based Industries					Non-Knowledge-Based Industries				
	L	*E*	*M*	*K*	*ICT*	*L*	*E*	*M*	*K*	*ICT*
PL	-0.03	-0.14	0.40	0	0	-0.15	0.05	0.14	0	0
PE	-0.14	-0.03	1.27	0	0	0.05	-0.09	0.70	0	0
PM	0.40	1.27	-1.00	0	0	0.14	0.70	-0.89	0	0
CK	0	0	0	0	0	0	0	0	0	0
CICT	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
Q	0.96	0.83	0.03	0	0	0.95	0.87	0.03	0	0
	Long-run Elasticities									
PL	-1.60	0.25	0.95	0.90	0.93	-0.83	0.09	0.54	0.71	0.94
PE	0.25	-0.16	1.00	0.36	-0.98	0.09	-0.10	0.99	0.27	-0.30
PM	0.95	1.00	-1.00	-0.93	0.98	0.54	0.99	-0.91	-0.75	-0.40
CK	0.90	0.36	-0.93	-0.91	0	0.71	0.27	-0.75	-0.88	0
CICT	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
Q	0.97	0.85	0.17	1.00	1.00	0.96	0.88	0.13	1.00	1.00