Chapter 4
The Factor Demand Model and the Theory of Productivity

This chapter outlines the background of the problem, along with presenting the relevant theories and existing researches related to the analysis of the productivity growth. The development of factor demand models is explained in detail based on the framework of the theory of firm's optimal input decisions in a non-static context. The framework consists of different concepts (i) the firm's temporary equilibrium which differentiates between the short run and the long run equilibrium. It relies on the distinction between production possibilities that are immediately feasible and those that are only eventually feasible. 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. (ii) The adjustment cost: Some inputs such as energy use and materials are more likely considered as variable input factors of production; their use is often depending on the amounts of capital equipment and structures that are fixed in the short run. The adjustment of these inputs in response to a price shock will be complete only after the capital input is capable to re-equilibrate. 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. (iii) The dynamic factor demand: The cost minimization goal of the producer is subjected to a number of restrictions: The production process and its capacity in producing maximum quantity of output given the level of inputs are available, 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. 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. The results in general indicate substitution between capital and labor, while complementarity between

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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. Literature on economic growth have concentrated more on studying and identifying the determinants of TFP as the drive engine of long run economic growth. 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 the industrial sectors.

4.1 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.

4.1.1 The Firm's Temporary Equilibrium

The temporary equilibrium is a term originated from the Marshallian distinction between short run 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 they are 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 its 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).

4.1.2 The Adjustment Cost

Studies related to firms' 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 cost (Nadiri and 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 some input factors of production such as energy and materials are more likely considered as variable inputs, their use is often depending 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 et al. 1981).

The concept of the adjustment cost was first considered in the neoclassical theory of the firm by Eisner et al. (1963), refined by Lucas (1967), and further by others. There are two types of adjustment cost often suggested by literature, first, the 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 cost 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.

In the absence of adjustment costs for the use of input factors of production, the firm's dynamic problem would become unrealistic, in which all input factors of production would be continually adjusted and their marginal contribution to profits will be equal to their rental costs. However, in reality, the input factors of production cannot be used without incurring the adjustment cost. Building and Machinery need to be installed, workers have to be trained, compensation payment have to be paid to dismissed workers, second hand capital equipment has much lower value than new capital equipment, and is often so specialized that can be only sold to firms that are facing by the same exogenous uncertainty. In such situations capital has value only if it is used in production, and capital accumulation is irreversible. Realistic adjustment costs are non-negligible even for small adjustment in the uses of input factors of production, the assumption that they are in fact linear does less violence to reality than the more usual assumption of quadratics adjustment costs (Bertola 1998).

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).

4.1.3 The Dynamic Factor Demand

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 three generations of the dynamic factor demand models have been recognized by Berndt et al. (1981) and Berndt and Morrison (1981). 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 and Prucha 1986).

The role of economic theory was limited to the specification of equilibrium input levels. Later developments which relied on the concept of adjustment cost 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 of 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 that 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 and 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 factors of production can be treated in the short run as variable inputs. 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 U.S. manufacturing, Schankerman and Nadiri (1982) by using U.S. 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 cost within temporary equilibrium framework. The quadratic form is suitable to incorporate the restriction of separability of adjustment cost 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 values of estimated adjustment cost 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 (i) The production process and its capacity in producing maximum quantity of output given the level of inputs are available and used, (ii) A fixed capacity of the firm during a certain time period, (iii) Knowledge of price and availability of different inputs used in the production process, and (iv) 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 and Timilsina 2009).

A key hypothesis required to determine the demand for input factors of production is the profit maximization, which depends on the level of output and limited combinations of input factors that give a highest level of 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.

4.2 The Industrial Demand Models 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 cost for quasi fixed inputs.

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 the 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 et al. (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 et al. 1977; Battese and Coelli 1995; Jondrow et al. 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 et al. 2000; Kumbhakar et al. 2002; Masso and 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. Their 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 U.S. 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 U.S. 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 substitutability. In one example, Jones (1995) analyzed the inter-fuel substitution of the U.S. 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.

4.3 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 U.S. 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 U.S. 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 U.S. 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 et al. (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 et al. (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 U.S. 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 et al. (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 and capital have substitutability relationship. Harper and Field (1983) estimated the elasticity of substitution for capital, labor, materials, and energy for the U.S. 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 substitutes, 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 et al. (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 sectors.

A study conducted by 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 sectors using pooled time series data and covering the period of 1960–1980. They found substitutability of energy and capital in the total manufacturing and total industry level, while complementarity was found in some others sub-industrial sectors.

The factor demands of manufacturing sectors in the US and Japan is investigated by Morrison (1988) to characterize the short and the long run price elasticities of demand. The author found that in both countries the energy and capital are complement, while other inputs are substitutes. A literature survey conducted by Apostolakis (1990) on energy and capital relationship showed that studies used time series data and methodology to capture the short run effects have 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 et al. (1991) investigated the elasticity of substitution for capital, labor, and energy in the manufacturing sectors in India, Pakistan, and Bangladesh using Translog cost function. They showed that capital and energy have substitutability relationship, 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 U.S. manufacturing sectors. The study found the substitutability between capital and energy in both countries. Watanabe (1992) through investigating the substitutability of energy and capital for Japanese manufacturing sectors during the period of 1970–1987 argued that the energy and capital substitution was 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 of 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 of 1978–1990 to estimate the 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 of 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 of 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, 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 of 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 of 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 input 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 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 of 1980–2007.

Based on the literature, Stern (2011) argued that the relationship between energy and output can also be affected by the following factors (i) The substitution between energy and other inputs, with the literature providing varying conclusions, (ii) Technological change, and the rebound effect, (iii) 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 finally (iv) Shifts in the composition of output (different industries have different energy intensities.

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.

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 study in order to identify behavioral characteristics of individual industry, and to derive relevant specific policy variables and recommendations.

4.4 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 and Soete 1997; Grossman and Helpman 1991; Lucas 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 and Bosworth 1996;

Krugman 1994; Stiglitz 1996). Accordingly the literature on economic growth have concentrated more on studying and identifying the determinants of the TFP as the drive engine of long run economic growth (Kim and 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 et al. 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 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 (Hsiao and 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 and 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 et al. (1994) applied the 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.

From the above, one my notice that the index has gained a noticeable increase in popularity, the reason 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 (Chen et al. 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.

A 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 and 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 Lee et al. (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 et al. 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 and Luh 1999; Cook and Uchida 2002; Kim and Park 2006; Kruger et al. 2000; Taskin and Zaim 1997).

4.5 Summary

This chapter has discussed in detail 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. 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 study adapted the dual approach in estimating the production structure of the South Korean and Japanese 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 have the advantage of deriving the elasticities as well as accounting for responsive heterogeneity over time and by industry characteristics.

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 heterogeneity across industries in unmeasured determinants of the factor demand.

Most of the studies related to the South Korean productivity measurement have mainly applied non-parametric approach to estimate the TFP at the country aggregated level, or at the microeconomic 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.

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