MULTILATERAL COMPARISONS OF TOTAL FACTOR PRODUCTIVITY IN MANUFACTURING INDUSTRIES OF SELECTED OECD COUNTRIES

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PREFACE

The differences in relative industry productivity across countries are of interest and importance for several reasons. The difference in total factor productivity (TFP) explains comparative advantage, international differences in price structure, and gaps in income and growth across countries. Productivity comparison by industry is attracting interest because the overall TFP comparison to the economy has strong assumptions such as the same production function and identical factor prices over all industries. In practice, these assumptions can rarely be fulfilled so that a less restrictive industry approach is favored. Irrespective of the sizes of manufacturing industries in the economy, the industries are important contributors to economic growth. The reason is that manufacturing generates much new technology and has big spillover effects on other sectors of the economy. TFP has been actively studied to explain productivity differences across countries or over time, because TFP analysis is one of most comprehensive ways of comparing relative industry productivity across countries. Productivity comparisons across countries require a multilateral productivity index based on the Malmquist index. The TFP index of CCD (Caves, Christensen, and Diewert) preserves transitivity in TFP comparisons across countries. Employing CCD TFP, this dissertation explores multilateral TFP comparison of manufacturing industries in 12 OECD counties since 1980 and identifies changes in TFPs over time and across countries. Employing the stochastic frontier production, the dissertation also investigates the effects of institutional factors on economic performance in terms of technical inefficiency in manufacturing industries. Institutional factors considered are economic freedom, market openness and the degree of corruption.

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A_t	Hicks-Neutral Technology or Hicksian Efficiency Index
Y_t	Outputs or Value Added
L_t	Labor Input
K_t	Capital stock
$F(\cdot)$	Neoclassical Production Function
F_L	Marginal Product of L_t
F_K	Marginal Product of K_t
$\dot{A}_t / A_t$	Solow Residual
$\hat{A}_{i,t}$	Productivity Gap
α_k	Cost Share of Labor Type *k* (Occupational Category)
$\Im_l$	Output Elasticity of Labor
$\Im_k$	Output Elasticity of Capital
s^K	Capital Share
s^L	Labor Share
δ	Depreciation Rate ($\delta < 1$)
w_k	Wage (*per hour*) of the Occupational Category *k*
λ	Speed of Convergence
δ_{ijt}	Rate of Technology Transfer
$\pi_{usa\ jt}$	Value Added Deflator
ppp^k_{ct}	Purchasing Power Parity used to Convert Capital Stock

r_j	Share of Total Value Added by Sub-Manufacturing Branch j
$-u_{it}$	One-sided Error Term Indicating Inefficiency
$F^c(x_c)$	$F(\cdot)$ of Country c with Country c's Technology
$F^c(x_d)$	$F(\cdot)$ of Country d with Country c's Technology
R_i^j	Revenue Share
W_i^j	Cost Share for a Country
TE_i	Technical Efficiency of Country i
TFP_{xusa}^j	Country x's TFP of Industry j relative to U.S TFP
MTFP	Multilateral Total Factor Productivity
CCD TFP	TFP of Caves, Christensen and Diewert
CRS	Constant Returns to Scale
GK	Geary- Khamis
EKS	Elteto-Koves-Szulc
ICP	International Comparison Project
PPPs	Purchasing Power Parities
UVRs	Unit Value Ratios
OECD STAN	OECD Structural Analysis
EMPN	Total Employment, Number Engaged in the OECD STAN Data
GFCF	Gross Fixed Capital Formation in the OECD STAN Data
BEA	Bureau of Economic Analysis
BLS	Bureau of Labor Statistics
ISIC 3	Manufacturing Sector
ISIC 31	Food Products, Beverages and Tobacco
ISIC 32	Textiles, Textile Products, Leather and Footwear

ISIC 33	Wood And Products Of Wood and Cork
ISIC 34	Pulp, Paper, Paper Products, Printing and Publishing
ISIC 35	Chemical, Rubber, Plastics and Fuel Products
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Chapter I.

INTRODUCTION

1.1 Overview of the Industry TFP Comparison

The differences in relative industry productivity across countries are of interest and importance for several reasons. They can help to explain comparative advantage and international differences in price structure, providing insight into the determinants of international trade. Moreover, these differences may explain differences in income and growth among countries. In particular, an industry-based quantitative approach to the study of economic growth is motivated by the possibility that comparative studies of productivity levels from a sectoral perspective might be more appropriate in explaining the slowdown of the world economy since the 1970s, the slow recovery of the 1980s, and the low growth rate in the 1990s. Finally, whether growth spreads evenly over countries and regions depends to some extent upon whether industries, not at the technological frontier are able to move to the frontier.

Furthermore, productivity comparison by industry attracts interest because the approach to the economy as a whole is based on strong assumptions such as the same production function and identical factor prices over all industries. In practice these assumptions can rarely be fulfilled so that a less restrictive industry approach is favored. In fact, empirical studies show that there exist large differences in estimates of productivity growth for the total economy constructed from the industry level compared to those constructed with an aggregate approach.

Productivity comparisons in the manufacturing sector are important for explaining economic growth as a whole, even though its share of the economy has been getting smaller over time. In the advanced countries, the manufacturing shares of output and employment in the total economy are much smaller than at the beginning of the postwar period (Wagner and Ark, 1996). During the 1980s and early 1990s, generally speaking, in lower income countries, which were less industrialized than in the advanced countries, the manufacturing sector still did not achieve the relative size at which the advanced countries had already reached. Irrespective of the size of manufacturing sector in the economy, however, manufacturing is usually considered an important contributor to economic growth. The reason is that the manufacturing generates much new technology and has important spillover effects on other parts of the economy, i.e. agriculture and services (Van Ark, 1996; Wagner and Van Ark, 1996).

In general, productivity research for the economy as a whole has been studied from the various viewpoints such as technological progress, comparative advantage, competitiveness, structural change and the analysis of catch-ups and convergence. These multiple spectrums arise because productivity comparisons are conceptually interdependent with other economic indicators such as accumulation of physical and human capital, technological progress and resource allocation including technical efficiency (Van Ark and Dirk Pilat, 1993).

Total factor productivity (TFP), in particular, has been actively studied to explain sectoral productivity differences across countries or over time, because TFP analysis is one of most comprehensive ways of comparing relative industry productivity (Wagner and Van Ark, 1996; Harrigan, 1997). TFP measures the output produced by given a quantity of inputs, say labor and capital (Dollar and Wolff, 1993). Therefore, a high level of TFP indicates good economic performance. For a long time, TFP has been measured by using time-series approach to growth accounting (Islam, 1996).

Solow showed that the growth rate of TFP could be measured by a formulation in which the growth of real output could be factored into the growth rate of capital stock and labor, both weighted by their elasticities, and the growth rate of the Hicksian efficiency index (Solow, 1957; Romer, 1996; Hulten, 2001). Solow's work proves theoretically that the growth rate of the Hicksian efficiency index is the difference between the growth of output and the weighted growth of inputs. This growth difference, TFP growth, is sometimes called the Solow residual, because it is the growth of output, which is not accounted for by the growth of inputs, i. e., the residual.

Abramovitz (1956) describes the Solow residual as a "measure of our ignorance". This is because it does not identify which of the many possible components of the residual such as the effects of technological and organizational innovation, imperfect measurement, aggregation errors, and model misspecification. Romer (1996) notes that this Solow residual is sometimes interpreted as a measure of the contribution of technological progress, even though it reflects all sources of growth other than the contribution of capital accumulation via its private return.

As Hulten (2001) says

> *TFP may be influenced by many factors such as technological innovation, organizational and institutional change, shifts in societal attitudes, fluctuations in demand, changes in factor shares, omitted variables, and measurement errors.*

Consequently, TFP studies still do not agree on "what are the real factors producing a high level of TFP". This is because in the accounting method of measuring TFP growth, all of these possibilities are together as a residual, rather than being directly measured.

The growth rate of TFP is useful for productivity comparison under a given country or region at different points in time, but is not as useful in comparing the relative productivity of different countries or regions (Hulten, 2001). Furthermore, the literature on convergence theory predicts that the growth rate of TFP would not be a good measure for comparing technology levels and growth across countries, because a less developed country may, for example, have a more rapid growth of total factor productivity than a developed country because of convergence. This convergence phenomenon is attributed to the fact that a less developed country begins with a lower level of output because of inferior technology, and thus can use advanced technologies, which have been developed elsewhere (Romer, 1996, pp.27)[1].

Productivity comparisons across countries require a different framework, a framework that was developed in a series of studies in the late 1970s and the early 1980s (Jorgenson and Nishimizu, 1978; Christensen, Cummings and Jorgenson, 1981). In particular, Caves, Christensen, and Diewert (1982a, 1982b) developed a multilateral productivity index based on the Malmquist index. The Malmquist index basically answers the following questions: how much output would country ***A*** produce if it used country ***B's*** technology with its own inputs? Or the complementary question, how much output would country ***B*** produce if it used country ***A's*** technology with its own inputs? The Malmquist TFP index is the geometric mean of the answers to the two questions. Using the Malmquist index, Caves, Christensen, and Diewert (CCD) developed a

[1] See, Romer (1996, pp.27): He provides in detail several reasons for convergence.

multilateral TFP index that preserves transitivity in TFP comparisons across countries. Harrigan (1995, 1997) uses this multilateral TFP index in order to compare the relative productivity at the industry level (Non-electric machinery, Office and Computing Equipment, Electrical Machinery, Radio and TV Communication Equipment, Motor Vehicle and Aircraft) for 10 OECD countries.

1.2 Theoretical Issues and Approaches of Productivity Comparison

In studying the differences in industry TFP across countries, one of key questions is "what are the determinants of TFP differences?" One of main interests in international TFP comparison is the extent that differences in TFP are related to differences in technology, because it is said that there could not be large differences in technology across countries at the same time horizon under the standard neoclassical trade theory (Islam, 1999).

From a theoretical viewpoint, the main distinction between Ricardian and neoclassical trade theory is the assumption regarding technology. Ricardian theory allows for long-term differences in technology and TFP across countries. Neoclassical trade theory, however, assumes an identical technology to all countries and the CRS (constant returns to scale) technology (Harrigan, 1997 and Islam, 1999). It should be noted that one of important implications of these assumptions in neoclassical trade theory is that TFP of each industry is the same across countries, indicating that a given quantity of inputs will produce an equal amount of output in every country. Islam (1999) notes that if this is the case, then outputs will differ across countries only due to differences in factor endowments.

There are, however, systematic differences across countries in industry outputs that cannot be explained by differences in factor endowments (Harrigan, 1995; Durlauf and Johnson, 1995). These results imply that the assumption of identical production technology may not be appropriate. These studies note that if technology is not the same across countries, then much of the theoretical work based on the neoclassical assumption is irrelevant to applied research on cross-country comparisons. The finding that technology is not the same across countries, in particular, has gained greater attention from several studies (Trefler, 1993, 1995; Dollar and Wolff, 1993; Harrigan 1997).

Harrigan (1997), however, provides several explanations on why TFP differences might be found with an assumption of identical technology. First, TFP differences could be the result of a mismatch between the theory of TFP comparisons and the technological and measurement processes that generate the data. Second, if increasing returns to scale exists at the level of industry, then countries with larger industry outputs will have higher measured TFP, even if technologies are identical. Third, if there is imperfect competition in output or input markets, then labor's share of total factor payments need not to correspond to labor's share of total costs, which could result in the finding of TFP differences. Fourth, if there is a substantial measurement error in inputs and/or outputs, then TFP may also appear to be different even if the underlying technologies are the same.

In general, there are two approaches to characterize TFP differences across countries, expressed as the expenditure approach and the industry of origin approach. The expenditure approach focuses on productivity comparison by expenditure categories such as private and government consumption and capital formation, while the industry of origin approach deals with sectors of the economy, such as agriculture, industry and services, and branches and industries within these sectors.

For output or productivity comparison of the economy as a whole, the expenditure approach is easier to use than the industry-of-origin approach. This advantage comes from the accounting measure in the expenditure approach, which is based on final products, thus avoiding the double counting of intermediate inputs. Furthermore, as a conversion factor, purchasing power parities (PPPs), which are derived from the expenditure side, are more readily and widely available than similar conversion factors (Unit Value Ratio UVRs) by the industry-of-origin approach.

With this breakdown, studies vary in their level of disaggregation and their country coverage. TFP comparisons using a value added output measure include those of Dollar and Wolff (1993), Dollar et al. (1988), Maskus (1991), van Ark (1993, 1996), and van Ark and Pilat (1993). Another approach using gross output deflates all inputs (capital, labor, materials, energy, etc.) in a symmetric way. This procedure, pioneered by Jorgenson in various studies is the ideal way to make productivity comparisons (Jorgenson, 1990; Harrigan, 1995, 1997), but the necessary data often aren't available.

1.3 Institutions and Inefficiency

Over the past decade, the role of institutions has been emphasized in explaining the differences in economic performance across countries in recognition of the increasing awareness of the importance of institutions for economic growth. In the neoclassical growth theory investment activity is considered the engine of economic growth. Over the past 10 years, however, institutions have been considered as most important factors in explaining economic performance, particularly through their influence on the investment activity of economic agents.

In answering what factors are making the economic performance differ across countries, Jones (1997) lists institutional factors such as the size of the market, the extent to which the economy favors production instead of diversion, and the stability of the economic environment. Furthermore, he described some activities such as theft, corruption, and the payment of "protection money", as institutional factors, not conducive to good economic performance. Confiscatory taxation by the government, on the other hand, represents legal diversion that has adverse effects.

According to Jones (1997), the first effect of diversion on the economy is that it acts like a tax and the second is that it encourages investment by the entrepreneur in finding ways to avoid the diversion. Because the extent to which the infrastructure of an economy favors production or diversion is primarily determined by the government, a measure of the extent to which government promotes good economic performance should explain efficiency differences across countries. Thus, this study postulates that economic freedom is a determinant of economic efficiency. The government could be itself a main agent of diversion, since economies with infrastructures that favor diversion may be built up by the government's abused tax-power, red-tape, and bureaucratic regulation. On the other hand, it is worthwhile to note another argument of Jones (1997), which says that economic performance might be influenced by the stability of the economic environment, implied by the fact that an economy in which the rules and institutions are changing frequently may be a risky place in which to invest.

During the last 10 years, numerous studies estimated the effects of institutional factors on the growth rate and the productivity of economy as a whole. Institutional factors are represented by various measures, depending upon the study's purpose. Economic freedom is one of the institutional factors emphasized, because it can proxy the extent to which the economy favors production instead of diversion. Another important institutional factor is market openness, which affects the size of the market.

Dawson (1998) shows that economic growth is associated with economic freedom by explaining the positive effect of economic freedom on investment activity and the level of total factor productivity (TFP). Another finding of Dawson's work is that political freedom is associated with higher investment.

Edwards (1998) argues that TFP growth is heavily influenced by initial per capita GDP, initial level of human capital, and openness. His work analyzes the relationship between openness and total factor productivity (TFP) by using 9 alternative indexes of trade policy. His study concludes, "countries with a lower degree of external distortions have tended to have faster productivity growth. More open countries will tend to have faster productivity growth than more protectionist countries".

Rodrik (1997) also argues that economic performance can be affected by political factors. His arguments are that democracies are associated with (a) more stable long-run growth rates, (b) greater short-run stability, (c) better ability to deal with adverse shocks, and (c) higher wages (Rodrik 1999). Furthermore, Rodrik (2000) documents the relationship between economic performance and institutions, by describing several types of institutions that permit markets to work adequately, such as property rights, regulatory institutions, institutions for macroeconomic stabilization, institutions for social insurance, and institutions of conflict management. In summary, he says, "democracies perform better on a number of dimensions: they produce less randomness and volatility, they are better at managing shocks, and they yield distributional outcomes that are more desirable. One interpretation of these results, and the one that I have emphasized throughout, is that democracy helps build better institutions" (Rodrik, 2000, pp. 34).

In a study closely related to this dissertation, Adkins, Moomaw and Savvides (2002) provide empirical evidence "that institutions, in particular institutions that promote economic freedom, affect economic performance". Their finding is that increases in economic freedom are associated with improved economic performance in that increases in it move countries closer to the production frontier. In other words, the study shows that countries with higher degrees of economic freedom tend to lie closer to the world production frontier.

Methodologically, there are broadly two different approaches in explaining the relationship between institutional factors and economic performance. The first approach is to investigate how institutional factors influence output growth, TFP growth, or unemployment as being shown by Dawson (1998), Edwards (1998) and Rodrik (1997, 1998, 2000).

The second approach is to identify the influence of institutions on technical inefficiency of the economy. Differences in economic performance could be explained by different countries operating at different distances from the production frontier (Adkins, Moomaw and Savvides, 2002). Their study is based on the idea that technical inefficiency, as measured by deviations from the production possibility frontier, is a function of certain measurable economic and institutional variables. Under this approach, Adkins et al (2002) estimate the extent to which economic and political institutions contribute to technical inefficiency, or deviations from a stochastic frontier, rather than how they influence output growth, TFP growth, or unemployment.

In investigating the differences of productive performance across countries of any specific industry, there is a wide spectrum of possible explanations ranging from physical factors to institutional factors. One example comes from Baily and Gersbach (1995), who explain the productivity difference of manufacturing industry by capital accumulation, optimal economic scale, proprietary technology, workplace organization and labor skills.

Griffith et al (2001) provide evidence that research and development (R&D) stimulates growth directly through innovation and also indirectly through technology transfer. Scarpetta and Tressel (2002) also find evidence that the impact of R&D on productivity depends on market structure and technological characteristics. In particular, their study documents that anti-competitive product market regulations are negatively associated with productivity performance. They argue that the negative effect is larger the further a country is from the technological frontier, because such regulations hinder the process of technology adoption. Finally, there is also evidence on the negative impact of tight employment protection legislation on productivity because wages or internal training does not offset the higher adjustment costs associated with high firing costs.

Methodologically, there are only a few studies that investigate the influence of institutions on technical inefficiency of a specific industry under the manufacturing sector by measuring deviations from the production possibility frontier. Even though several studies (Adkins et al, 2001; Klein and Luu, 2002) attempt to investigate economic performance by using a stochastic frontier approach, they focused on the economy as a whole instead of any specific industry. One reason for the small number of studies of the effects of institutional factors on economic performance (measured by technical inefficiency) of a specific industry using the stochastic frontier approach is the lack of the necessary data.

1.4 Objectives of the Dissertation

1.4.1 Derivation of Multilateral TFP Index for Manufacturing Industries

This dissertation explores multilateral comparison of total factor productivity (TFP) of the manufacturing sector as a whole and in 9 manufacturing branches in 12 OECD counties since 1980. The 12 countries are Austria, Belgium, Canada, England, Finland, France, Italy, Netherlands, Norway, Korea, Sweden and United States. It characterizes and computes TFP index by industry in the manufacturing sectors across OECD countries by using a panel data on value added, gross fixed capital formulation, and employment for OECD countries during 1970-1998. To this end, this dissertation follows index number theory (Caves et al, 1982) and its application (Harrigan, 1995, 1997 and 1999). The dissertation produces a set of multilateral TFP index by sub-industry, which is expressed by the 2 – digit ISIC classification under the manufacturing industry. New OECD data are used to establish new evidence regarding Harrigan's (1997) statement "that there exist systematic differences across countries in industry outputs in terms of TFP that cannot be explained by differences in factor endowments".

The new estimates of TFP comparison documents how large and persistent the TFP differences were across countries and industries during the 1980s and 1990s. These new estimates extend the comparison figures of TFP across OECD countries to the late1990s, in comparison to earlier studies that stopped in 1992[1].

1.4.2 Analysis on TFP Convergence

Convergence studies across countries have concentrated heavily on the labor productivity, using GDP per capita as the productivity measure. As Bernard and Jones (1996a, 1996b) emphasize, many studies (Baumol, 1986: Barro and Sala-i-Martin, 1991, 1992: Mankiw et al, 1992) research productivity convergence for the entire economy, rather than for a sector or an industry. However, some studies (Broadberry, 1993; Bernard and Jones, 1996) provide evidence, showing little or no convergence in productivity for the manufacturing sector. This dissertation examines the changes in productivity trends in 12 OECD countries by industry. The dissertation identifies changing trends of TFP over time and across countries by a specific industry by using a multilateral TFP index, which is derived on the basis of the Malmquist index theory and the convergence model of Bernard and Jones (1996).

1.4.3 TFP growth and Research and Development Activity

The dissertation shows that there are consistent differences in TFP levels of manufacturing industries across 12 OECD countries. As convergence theories suggest, differences in the TFP level are getting smaller over time (β-convergence) and the TFP discrepancies across countries (σ-convergence) are getting narrower.

[1] See, Harrigan (1997), Wagner and van Ark (1996) and Dollar and Wolff (1993).

Griliches (1998) states that all productivity growth is related to all expenditure on R&D and implies that study on economic growth should estimate statistically the part of productivity growth that can be attributed to R&D. In fact, there are many studies on the links between R&D activity and TFP growth, undertaken at the whole-economy level. Only recently, however, have some studies investigated the relationship between R&D activity and TFP growth at the industry basis.

So, as a further step, this dissertation investigates within an empirical framework whether technology transfer or R&D activity takes an important role of determining TFP growth on a specific industry level for a country behind the technological frontier. The frontier in technology is defined as the country with the highest level of total factor productivity (TFP). To be more specific, the dissertation examines whether R&D activity has a direct effects on TFP growth of non-frontier countries, which could be termed as "innovation channel". In addition, the dissertation tries to investigate whether TFP growth depends upon a country's level of TFP relative to the frontier as an "imitation or adoption channel". The dissertation follows the econometric model specification of Griffith et al (2000).

1.4.4 Analysis on the Inefficiency Effects of Institutional Factors

The stochastic frontier production part of the dissertation investigates the effects of institutional factors on the technical inefficiencies of manufacturing industries for 12 OECD countries, using the OECD STAN 2002 data set. The dissertation confirms that a country's institutions might cause TFP differences in terms of inefficiency across countries. In more specific term, the object of the dissertation is to provide estimates of the determinants of technical inefficiency.

Institutional factors considered are economic freedom, market openness, and the degree of corruption. In particular, the dissertation provides and tests statistical evidence on whether the statement of Adkins, Moomaw and Savvides (2002) below holds in a specific industry under the manufacturing sector:

"Institutions, in particular institutions that promote economic freedom, affect economic performance: Increases in economic freedom are associated with improved economic performance in that increases in it move countries closer to the production frontier."

1.5 Organization of the Dissertation

The remainder of the dissertation is organized as follows. Chapter II provides the concepts and important properties of conversion factors, which are required for productivity comparisons. In fact, choosing a conversion factor is the first step for comparing the productivity levels of a specific industry across countries. Chapter III provides theoretical frames of the productivity measures (productivity formulations), which are expressed by TFP index. In addition, all kinds of data requirements for calculating the Malmquist TFP index are defined in detail and the calculations are described step by step. Chapter III also presents TFP results, which are obtained by using the Caves, Christensen, and Diewert index theory, and provides the productivity trend across countries over time. Chapter IV shows the law of motion on the systematic differences in the productivity levels over time in terms of catch-up and convergence.

And the final part of this chapter is a study on the factors which cause the gaps in productivity levels across countries to narrow. Chapter V presents the model setting of the stochastic frontier approach for investigating the links between institutional factors - specifically, economic freedom, market openness and corruption – and inefficiency in a country's manufacturing industries. This chapter provides empirical evidence indicating that institutional factors determine the economic performance of a specific industry as measured by technical inefficiency. The last chapter delivers the overall summary and conclusion of the dissertation.

Chapter II.

CONVERSION FACTORS AND PRODUCTIVITY COMPARISON

2.1 Overview

When comparing the level of GDP and relative productivity, it is necessary to employ conversion factors to convert values of outputs or inputs to a common currency (for example, U.S dollars), since they are generally measured in domestic currency of each country. TFP comparison entails a series of theoretical and practical questions on how to derive conversion factors for comparison of real output and productivity in a common currency, because international comparison of outputs and relative productivity depends largely on conversion factors (Schreyer, 1996).

There are three different types of conversion factors: exchange rates, purchasing power parities (PPPs) and unit value ratios (UVRs). These conversion factors have been employed differently for comparison purposes in various studies. The choice of conversion factor heavily depends on which approach is used for the TFP comparison. In general, for comparing output or productivity for the economy as a whole, either the expenditure approach or the industry-of-origin approach is applied. While the expenditure approach focuses on comparisons by expenditure category of the economy, the industry-of-origin approach is most appropriate for comparison of sectors or branches and industries within these sectors (Bart van Ark, 1996, chapter 1, pp.27).

O'Mahony (1996) sets out a list of criteria which the conversion factor should satisfy, so as to evaluate which conversion factor is more reasonable for a comparison purpose. He identifies five properties that a conversion factor should satisfy. They are:

Conceptual Correctness: A conversion factor should be compatible with the output data used for calculating relative productivity;

Complete Coverage: it should be based on a representative sample of goods or services for each sector for which productivity comparisons are estimated;

Intertemporal Consistency: it should be consistent with changes in relative prices in the intervening period implied by each country's domestic price indices;

Quality Adjustment: it should correct for differences in the quality of goods and services across countries;

Index number properties: it should satisfy certain well-regarded properties of index numbers, in particular, transitivity. Other desirable properties include absence of substitution bias and additivity.

2.2 Exchange Rates

The exchange rate is well known for not being an appropriate conversion factor because it is influenced by short-term capital movements. Furthermore, there could be huge variations in price ratios even in traded sectors across countries due to different economic conditions, such as a degree of monopoly power in a specific industry or a time-lag in response to exchange rate movements. In principle, exchange rates refer only to the relative prices for tradable goods and services (Bart van Ark, 1996). In non-traded sectors, even under an open economy, price ratios between countries cannot be expected to be close to the exchange rate. The market exchange rate may also be inappropriate conversion factor because of differences in industry characteristics, such as factor mobility. The service sectors, for example, represent industries where the inputs of production process consist largely of other services. In this sector, it cannot be assumed that price ratios are close to the exchange rate.

Table 2.1: Comparison of Conversion Factor: Exchange Rate, PPPs and UVRs of Manufacturing Sector (1987)

	Canada	France	Germany	Japan	U.K	USA
Exchange Rate	1.33	6.01	1.80	144.6	0.604	1.00
(National Currency/US$)						
Relative Price Levels (Currency Conversion Factor/Exchange Rate)						
ICP expenditure PPP						
Multilateral (EKS)	98	113	122	147	93	100
Bilateral (Fisher)	96	110	114	136	101	100
Proxy PPP	108	134	131	151	131	100
Unit value ratio (UVR)	101	120	123	120	117	100

Source: Bart Van Ark (1996), "Issues in Measurement and International Comparison Issues of Productivity – An Overview" Groningen Growth and Development Centre, University of Groningen.
Note 1) ICP expenditure PPPS, multilateral variant comes from OECD National Accounts, Vol. 1 (1993).
Note 2) ICP expenditure PPPS, bilateral Fisher variant are provided by EUROSTAT for 1990 and backdated to 1987 with GDP deflators.
Note 3) Proxy PPP is the "OPR" variant from Hooper and Vrankovich (1995) for 1990 backdated to 1987 with manufacturing GDP deflators.
Note 4) UVRs are ICOP estimates (see van Ark, 1996).

2.3 Purchasing Power Parities (PPPs)

Purchasing power parities (PPPs) are defined as the number of currency units required to trade goods equivalent to what can be bought with one unit of the currency of a base country (Kravis, Heston and Summers, 1982). Under the expenditure approach, PPPs are generally used as the conversion factors for comparison of output or productivity, since PPPs are derived on the basis of final expenditure prices. Estimates of PPPs are provided on a regular basis by the International Comparisons Project (ICP) begun by Kravis and his associates in 1950, to compare income per capita of the population.

PPPs are more readily and widely available than conversion factors by industry of origin. The expenditure PPPs, however, may not be appropriate for comparison of output and productivity at a sectoral level, because PPPs are derived based on the prices of final goods, services and capital formulation (van Ark, B, 1993). Using van Ark as a guide, the following are specific reasons why PPPs may not be appropriate for productivity comparison on a sectoral level.

Conceptual Criterion

In general, the use of PPPs as conversion factors is not appropriate in productivity comparisons at the industry level because a large portion of manufacturing output consist of intermediate products rather than final products for consumers. PPPs are more appropriate to evaluate and compare standards of living across countries because PPPs are based on final consumption prices measured at market prices.

Complete Coverage

The PPPs are based on final consumption prices; thus, they are not ideal conversion factors for productivity comparison in the manufacturing sector, which includes many intermediate products. PPPs, however, could be reliable conversion factors for specific industries producing final goods, such as distribution, hotels and catering, and personal and professional services.

Intertemporal Consistency

The conversion factors should be consistent over time with the trends of each country's expenditure or producer price indices. The intertemporal consistency of conversion factors depends on the intertemporal consistency at a disaggregated level. In particular, it should be noted that if comparison is based on PPPs, relative productivity comparison over time at a disaggregated level could be biased, because PPPs tend to vary considerably over time.

Quality Adjustment

The conversion factors are presumed to correct for differences in the quality of goods and services across countries. In reality, it is well known that PPPs suffer from problems in correctly measuring quality. The unit value ratios (UVRs) developed by van Ark (1993) are affected by differences in product mix and product quality. The product mix problem comes from the fact that statistics on the manufacturing census report quantities and values, which are based on product groups rather than on specified products. In the case of rapidly increasing numbers and varieties of goods and services, the problem of sampling bias and quality adjustment is expected to become serious (van Ark, 1993).

Index number properties

In general, index number theory shows that there is no single best index number in most applications. The choice of aggregation method depends on the particular application being considered. Transitivity is considered as the most desired property for productivity comparison. The transitivity property is not guaranteed by formation of bilateral price ratios, irrespective of types of conversion factors. For example, the price ratio derived by matching products in the country ***A*** relative to country ***C*** divided by the price ratio in country ***B*** relative to country ***C*** will not generally equal the price ratio in country ***A*** relative to country ***B***. This result is because the sample of products matched differs in each bilateral comparison. Furthermore, there could be differences in the weights used to aggregate prices at broad sectoral levels between countries (For discussion in depth, see van Ark, 1993 and 1996).

As a result, international bodies, such as Eurostat and OECD, use a multilateral formulation, under which transitivity property automatically holds. EKS (Elteto-Koves-Szulc) and GK (Geary Khamis) methods are the most commonly used aggregation for price ratios when multilateral parties are involved. While the EKS aggregation yields results close to that derived by bilateral Fisher price ratios, the GK method can produce results which extend beyond the range covered by the Laspeyres and Paasche price ratios (van Ark, 1993).

2.4 Unit Value Ratios (UVRs)

Under the industry-of-origin approach, the most generally used conversion factors are unit value ratios (UVRs), which are based on information on the sales values and on the quantities of goods and services produced in each country. Unit values are calculated by dividing the value of production at the ex-factory stage by physical output measures. UVRs are aggregated measures of these unit values as a ratio between countries on the basis of a specific industry. In fact, UVRs are excellent proxies of producer prices and of price ratios for intermediate goods. Therefore, UVRs are used, when possible, as conversion factor for disaggregated productivity comparisons (Van Bart Ark, 1996 and O'Mahony, 1996).

To derive UVRs for the manufacturing sector, it is necessary to formulate an aggregation on the basis of UVRs in a specific industry. In particular, the aggregation for deriving UVRs for the manufacturing sector as a whole is very important, because it is not possible to match all product items in the manufacturing sector. The aggregation procedure up to the level of total manufacturing is carried out in several stages. In order to derive UVRs between two countries (binary comparison), it is necessary to define manufacturing branches or industries that produce the same products in both countries. Product matches are categorized in as many similar product grouping as possible within each industry of two different countries. The average unit value ratio for the manufacturing sector or a specific branch is obtained by weighting the unit values by the corresponding quantity weights. (For discussion in depth, see van Ark, 1993, chapter 3, pp. 27-51).

Van Bart Ark (1996), however, points out that the UVR method has three major problems, which affect the comparability of the estimates across countries.

Limited sample of items: UVRs are based on a limited sample of items for productivity comparisons in many sectors and industries; thus, they may not be representative of the entire industry or sector. The average percentage of outputs covered by UVRs is between 15 and 45 percent in the manufacturing sector, but it is assumed that UVRs for matched items within the manufacturing branch are representative for non-matched items.

Table 2.2: Unit Value Ratios in the Major Manufacturing Sector (1987)
Number of Unit Value Ratios, Coverage Percentage

Country	Number of Product Matches	Matched Outputs as % of total		Unit Value Ratios			Exchange Rate
		Own Country	USA	Own Quantity Weights	US Quantity Weights	Geometric Average	
U.K	171	17.6	18.1	0.67	0.75	0.71	0.61
Finland	275	42.9	19.9	5.28	5.98	5.62	4.40
Sweden	248	34.5	21.8	7.78	8.3	8.03	6.34
Germany	271	24.4	24.8	2.16	2.25	2.21	1.80
France	109	15.1	12.5	6.87	7.59	7.22	6.01
Japan	190	19.1	19.9	149	203	174	145
Canada	200	27.8	21.6	1.36	1.31	1.33	1.33
Belgium				41.06	44.17	42.61	37.33
Netherlands	97	28.7	15.8	2.18	2.46	2.32	2.03
Mexico	130	31.8	22.8	11.97	15.60	13.67	12.50
Korea	190	36.7	21.0	577.0	849.0	700.0	823.0
Australia	178	23.1	15.1	1.41	1.58	1.49	1.43

Data Source: Bart van Ark and Marcel Timmer (2001), " PPPs and International Productivity Comparisons: Bottlenecks and New Directions", ILO Seminar on International Comparison (Jan 26, 2001) Geneva

Differences in product mix: UVRs are based on information obtained by production census, which presents output values for product groups rather than for specific products. Because of the lack of a harmonized product coding system for international comparisons, further aggregations of products are required in order to obtain a correct match across countries. Thus, differences in product mix may bias the unit values.

Differences in product quality: UVRs should be adjusted for differences in product quality across countries. Even though there are correct matches between product groups, it is almost impossible to have the same quality of products across countries and within one country over time. In particular, the most significant problem in the manufacturing sector, is that the portion of output covered by UVRs is often well below 15 percent. ***Table 2.2*** presents a country comparison of weighted UVRs by manufacturing branch. It is confirmed that the portion of output matches range from 12.5% (between the United State and France) to 42.9 % (Finland).

2.5 Conversion Factors and Productivity Comparison

PPPs are generally used as the conversion factors for comparison of output or productivity for the economy as a whole, because PPPs are derived from final expenditure prices. PPPs are a less appropriate conversion factor for productivity comparison of the manufacturing sector as a whole. However, PPPs can be a reliable conversion factor for specific branches of the manufacturing sector, which does not depend on the intermediate products of the production process. On the other hand, UVRs are utilized as proxies of producer price indices for intermediate goods. Therefore, the UVRs are an appropriate conversion factor for the manufacturing sector as a whole and its branches.

Due to conversion factor characteristics, the results of productivity comparisons are expected to be different based on the conversion factor employed. O'Mahony (1996) presents evidence in terms of labor productivities, which are constructed by PPPs and UVRs. ***Table 2.3*** indicates that the variation in productivity level that is caused by using different conversion factors. Different conversion factors chosen alter the comparative productivity position, as given by the productivity between Japan and other nations.

Table 2.3: Alternative Comparative Labor Productivity Estimates (Output per employee, United Kingdom = 100)

Country	Benchmark Year	Using 1985-based proxy PPP	Using 1990 based proxy PPP	Using UVRs
France	1984	107.9	101.1	117.0
Germany	1987	109.5	109.6	113.5
Japan	1987	108.3	119.4	159.6
United States	1987	174.8	174.3	186.7
United Kingdom	1984 or 1987	100.0	100.0	100.0

Note: The PPPs have been extrapolated to benchmark years using national GDP deflators.
Source: O'Mahony (1996), Table 1, p. 247.

The ICP PPPs have the advantage of being based on large samples of carefully matched products. In this case, productivity comparison is more representative and less affected by quality problems. On the other hand, UVRs have a conceptual advantage in specific sectors, in particular, in the manufacturing sector. Moreover, as ***Table 2.4*** indicates, UVRs provide detailed conversion factors by manufacturing branch, which are not available in the PPPs. Nevertheless, this dissertation uses PPPs because UVRs are only available for a few countries for a specific year 1985 or 1987, as shown in ***Table 2.2***.

The dissertation uses ICP PPPs as a basic conversion factor in converting all values of inputs and outputs into the values in terms of a common currency (1996 U.S dollar). More specifically, matching the expenditure ICP PPPs to industry classification under the International Standard Industry Code (ISIC), the dissertation constructs TFP indices of the manufacturing sector and its branches for 12 OECD countries. In the next chapter, the dissertation explains how ICP PPPs are used in obtaining the multilateral TFP index. It is important to recall the shortcomings of the PPP conversion factor in assessing the results presented in the next chapter.

Table 2.4: Exchange Rate, PPPs and Unit Value Ratios by Sub-Sector of Manufacturing (Base country = United States)

	Japan[a]	Korea[a]	Mexico[a]	U.K[a]	Canada[b]
Exchange Rate (1987) [c]	145	823	12.5	0.61	1.33
Expenditure GDP PPPs[d] (1985)	222	.	.	0.568	1.22
Unit Value Ratios (Geometric Average)					
(Base Year)	(1987)	(1987)	(1987)	(1987)	(1997)
Total manufacturing	181.5	699.7	13.66	0.708	1.32
Food Products	386.6	976.5	9.45	0.796	1.14
Beverage Products	429.5	552.9	13.33	0.588	.
Tobacco Products	395.0	752.9	8.45	0.476	.
Textiles	181.7	747.0	15.42	0.686	1.18
Wearing apparel	179.2	941.9	15.75	0.693	1.60
Footware and Leather Products	208.9	553.5	.	0.575	1.31
Wood products	471.5	1270.3	22.72	0.921	1.27
Paper, printing & publishing	188.1	645.2	19.74	1.048	1.32
Chemical products	229.5	1148.8	12.44	0.634	1.24
Petroleum Refining	313.2	.	.	0.645	.
Rubber and Plastic Products	121.3	791.2	19.01	0.549	1.41
Non-metallic Mineral	189.3	457.8	11.76	0.650	1.22
Basic Metal and Metal Products	178.4	694.0	11.89	0.664	1.35
Electric Engineering	143.4	491.4	18.40	0.740	1.41
Machinery & Transport Equipment	120.7	523.9	14.24	0.611	1.39
Other manufacturing	181.5	784.7	13.66	0.708	1.32

Data Source: a) Bart van Ark (1996), International Comparison of Output and Productivity: Manufacturing Productivity Performance of Ten Countries from 1950 to 1990, Groningen Growth and Development Center Monograph Series, No.1.
b) Bart Van Ark, Robert Inklaar and Marcel Timmer (2000),"The Canada-U.S. Manufacturing Productivity Gap Revisited: New ICOP Results" Groningen Growth and Development Centre, University of Groningen.
c) Bart van Ark and Marcel Timmer (2001), " PPPs and International Productivity Comparisons: Bottlenecks and New Directions", ILO Seminar on International Comparison (Jan 26, 2001), Geneva.
d) 1985 PPPs and Real Expenditures, OECD 1999.

Chapter III.

TFP MEASUREMENT AND PRODUCTIVITY COMPARISON

3.1 TFP Measure Formulation

In general, total factor productivity (TFP) measures the overall performance of the economy. Many factors make the TFP level different over time or across countries and regions. Therefore, in order to empirically investigate these TFP differences across countries and their causes, it is first necessary to measure TFP appropriately across countries, which in turn raises index number problems.

Solow (1957) tied the empirical study of total factor productivity to the aggregate production function. He postulated an aggregate production function with Hicks-neutral technology, given by the shift parameter (A_t), and constant returns to scale:

$$Y_t = A_t \cdot F(K_t, L_t) \tag{3.1}$$

where Y_t stands for output, L_t labor and K_t capital stock, and $F(\cdot)$ indicates the neoclassical production function with $\partial Y / \partial L \equiv F_L(\cdot) > 0$, $\partial Y / \partial K \equiv F_K(\cdot) > 0$, $\partial^2 Y / \partial L^2 \equiv F_{LL}(\cdot) < 0$ and $\partial^2 Y / \partial K^2 \equiv F_{KK}(\cdot) < 0$. The total (logarithmic) differential of this production function is:

$$\frac{\dot{Y}_t}{Y_t} = \frac{\partial Y}{\partial K}\frac{K_t}{Y_t}\frac{\dot{K}_t}{K_t} + \frac{\partial Y}{\partial L}\frac{L_t}{Y_t}\frac{\dot{L}_t}{L_t} + \frac{\dot{A}_t}{A_t} \tag{3.2}$$

Thus, the growth of real output on the left-hand side can be factored into the growth rates of capital and labor, both weighted by their output elasticities, and the growth rate of the Hicksian efficiency index. The input growth causes movements along the production function and perhaps factor substitution, while the growth rate of efficiency index shifts the production function (Romer, 1996, pp. 26; Hulten, Dean and Harper, 2001: pp. 8~11).

It is straightforward to show that with s^K and s^L defined as capital and labor's share, the growth rate of Hicks-neutral efficiency, the Solow residual, is:

$$\frac{\dot{A}_t}{A_t} = \frac{\dot{Y}_t}{Y_t} - s_t^K \frac{\dot{K}_t}{K_t} - s_t^L \frac{\dot{L}_t}{L_t} \tag{3.3}$$

The growth rate of the residual can be calculated with data on output growth, input growth, and factor shares; it is the growth rate of output not explained by the growth in inputs, which is the definition of TFP growth. Therefore, the growth rate of the Hicksian efficiency parameter measures TFP growth. It does not, however, measure growth in technology across countries—shifts in the production function—because it captures both improvements in technical efficiency and shifts in the production function.

To measure relative productivity levels, note that TFP is the ratio of value added (Y) to a weighted average of production inputs such as labor (L) and capital stock (K):

$$TFP_t^i = \frac{Y_t^i}{\alpha^i L_t^i + (1-\alpha^i) K_t^i} \tag{3.4}$$

where α is the wage share. This formulation represents the absolute level of TFP of a specific sector or industry for a country i. To compare two countries, a binary index can be created by TFP index with a TFP index for a base country, say the United States, for a specific year (1990) for the relevant sector (Dollar and Wolff, 1993; pp.67). Thus, the TFP level for total manufacturing in another country relative to the United States (Dollar and Wolff, 1993: pp.70), can be measured as:

$$\frac{TFP_t^i}{TFP_s^j} = \frac{Y_t^i / Y_s^j}{[\alpha^i L_t^i + (1-\alpha^i) K_t^i] / [\alpha^j L_s^j + (1-\alpha^j) K_s^j]} \tag{3.5}$$

where j stands for United States, i, the comparison country compared, and s, a specific year, 1990.

TFP is often calculated assuming a Cobb-Douglas production function, where α the partial elasticity of output with respect to labor equals labor's share. The Hicks-neutral efficiency parameter, term A_t is the TFP level at a specific point in time. Several studies calculate the relative level of TFP between two countries as:

$$\ln\left(\frac{A^i}{A^j}\right) = \ln\left(\frac{Y^i/L^i}{Y^j/L^j}\right) - (1-\alpha)\ln\left(\frac{K^i/L^i}{K^j/K^j}\right) \tag{3.6}$$

where α is the geometric average for two countries of the partial elasticity of output with respect to labor (Freudenberg and Unal-Kesenci, 1996; Dirk Pilat, 1996). A series of such bilateral comparisons, however, does not satisfy the property of circularity necessary to obtain a consistent set of multilateral comparisons.

3.2 The Malmquist Index for Multilateral TFP Comparisons

Caves, Christensen and Diewert (1982a and 1982b), using the Malmquist index, devised a consistent multilateral index, the CCD index, for comparing relative productivity levels across economic entities. This approach provides a basic framework for multilateral comparisons that preserves transitivity. The transitivity property is desirable for comparing more than two entities simultaneously. The Malmquist productivity index asks the simple question: if there are two countries, c and d, in comparison, how much output could country c produce if it used country $d's$ technology with $c's$ inputs. Or how much output could country d produces if it used country c's technology with its own inputs. The Malmquist index is the geometric mean of the answers to these two questions. Formally, let the production functions be:

$$y_j^i = F^i(x_j), \quad i, j = c, d \tag{3.7}$$

where subscripts stand for countries, inputs, and outputs, while superscripts indicate the technology being used. So, $y_c^c = F^c(x_c)$, stands for the production function in country c with technology c. Moreover, $y_d^c = F^c(x_d)$ means the production function for country d with technology c. The Malmquist approach estimates how much output y_c^d would have been produced in c if the technology of d had been applied to c's inputs, i.e., $y_c^d = F^c(x_c)$. Then, the ratio y_c^c / y_c^d is a measure of how much more (or less) productive is technology c compared to technology d at the c's input level. A similar calculation establishes the ratio y_d^d / y_d^c, which measures how much more productive technology d is when compared to technology c with the input level of country d (Caves, Christensen and Diewert, 1982b, pp.1314; Hulten, Dean and Harper, 2001, pp. 18~19).

The Malmquist approach shows that productivity comparisons can be viewed as output comparisons with input levels hold constant. Productivity comparison between two countries, say c and d, can be based on either c or d or on some average of them. The Malmquist index for productivity comparison is the geometric mean of these two ratios. As Caves et al. (1982a and 1982b) points out, the translog bilateral productivity index can make base-country invariant binary productivity comparisons. But a set of such binary comparison indexes does not satisfy the circularity requirement for multilateral productivity comparison. The index proposed by Caves et al. (1982) permits such transitive multilateral productivity comparisons.

Assuming that producers are cost-minimizers and price takers in input markets, they develop the following translog multilateral productivity index, which permits TFP comparison across multiple economic units:

$$TFP_{kl} \equiv \ln\lambda_{kl} = \frac{1}{2}\sum_i (R_i^k + \overline{R}_i)(\ln Y_i^k - \ln\overline{Y}_i) - \frac{1}{2}\sum_i (R_i^l + \overline{R}_i)(\ln Y_i^l - \ln\overline{Y}_i)$$
$$- \frac{1}{2}\sum_n (W_n^k + \overline{W}_n)(\ln X_n^k - \ln\overline{X}_i) + \frac{1}{2}\sum_n (W_n^l + \overline{W}_n)(\ln X_n^l - \ln\overline{X}_i) \qquad (3.8)$$

where Y_i^j is the output vector, X_i^j input vector, R_i^j revenue share and W_i^j cost share for a specific year ($i = ..1987..$) and entities compared ($j = k \ or \ l$), respectively. And the bar notation of each corresponding variable indicates the arithmetic mean over of the entities compared.

Harrigan (1997, 1999) expresses the same index as the geometric mean of two distance functions for any two countries *c* and *d*.

$$TFP_{cd} = \frac{y_c}{y_d}\left(\frac{\bar{l}}{l_c}\right)^{\sigma_c}\left(\frac{\bar{k}}{k_c}\right)^{1-\sigma_c}\left(\frac{l_d}{\bar{l}}\right)^{\sigma_d}\left(\frac{k_d}{\bar{k}}\right)^{1-\sigma_d} \qquad (3.9)$$

where y_i stands for output or value added of country i, l_i labor input, and k_i capital stock, respectively. The bar variable denotes an average over all the observations in the sample. And $\sigma_j = (s_j + \bar{s})/2$, where s_j is labor's share in total cost in observation *j*. In addition, Harrigan's shows that if the value added function is Cobb-Douglas, the index is:

$$TFP_{cd} = \frac{y_c}{y_d}\left(\frac{l_d}{l_c}\right)^{s}\left(\frac{k_d}{k_c}\right)^{1-s} \qquad (3.10)$$

These TFP indices are superlative, meaning that they are exact for the flexible translog functional form. In particular, the CCD TFP index satisfies the circularity property that:

$$TFP_{bd} = TFP_{bc} \cdot TFP_{cd} . \qquad (3.11)$$

Circularity makes the choice of base country and year inconsequential and coping with the limitation of the bilateral TFP index (Harrigan, 1997, pp. 480; Caves, Christensen and Diewert, 1982a, pp. 81).

In this dissertation, the multilateral TFP index is used to measure the differences in TFP of specific industries across OECD countries and over the 1980s and 1990s. For measuring the difference of industry TFP, taking the U.S.A as a base country, the multilateral TFP index is

$$TFP^j_{x\,usa} = \frac{y^j_x}{y^j_{usa}} \left(\frac{\bar{l}^j}{l^j_x}\right)^{\sigma_x} \left(\frac{\bar{k}^j}{k_x}\right)^{1-\sigma_x} \left(\frac{l^j_{usa}}{\bar{l}^j}\right)^{\sigma_{usa}} \left(\frac{k_{usa}}{\bar{k}^j}\right)^{1-\sigma_{usa}} \qquad (3.12)$$

where $TFP^j_{x\,usa}$ stands for TFP level of industry j in terms of U.S TFP level of the same industry. y^j_i is value added of industry, l^j_i ,labor input and k^j_i capital stock of industry j, respectively.

The multilateral TFP index for the manufacturing as a whole, as formulated by Harrigan (1997, 1999) is:

$$TFP_{x\,usa} = \left[\prod_{j=1}^{N} \left(\frac{y_{xj}}{\bar{y}_j}\right)^{\rho_{xj}} \left(\frac{\bar{y}_j}{y_{usaj}}\right)^{\rho_{usa\,j}}\right] \left(\frac{\bar{l}}{l_x}\right)^{\sigma_x} \left(\frac{\bar{k}}{k_x}\right)^{1-\sigma_x} \left(\frac{l_{usa}}{\bar{l}}\right)^{\sigma_{usa}} \left(\frac{k_{usa}}{\bar{k}}\right)^{1-\sigma_{usa}} \qquad (3.13)$$

where $TFP_{x\,usa}$ stands for TFP level of the manufacturing sector in terms of TFP level of the manufacturing of U.S.A. $y_{usa\,j}$ stands for output or value added of country U.S.A, l_{usa}

total labor input employed in the manufacturing sector of U.S.A, and k_{usa}, total capital stock, respectively. The bar variable denotes an average over all the observations in the sample. And $\sigma_{usa} = (s_{usa} + \bar{s})/2$, where s_{usa} is labor's share in total cost in the manufacturing sector of U.S.A. $\rho_{usa\,j} = (r_{usa\,j} + \bar{r}_j)/2$, where $r_{usa\,j}$ is the share of total value added in U.S.A accounted for by sub-manufacturing branch j. Again, this formulation can be applied for any two distinct observations, such as different countries during the same year, two different countries in different years, or the same country in different years.

3.3 Accounting Factors for calculating TFP and Data Processing

3.3.1 Real Value Added

For deriving the multilateral TFP by manufacturing branch, value added is used as an output measure (y_i). To obtain consistent value added measures across countries, some adjustments are necessary, chiefly because value added is recorded in a country's domestic currency.

Value added is converted to real terms by using a national deflator and an index of purchasing power parity, using the following procedures as presented in Harrigan (1999):

$$y_{cjt} = Y_{cjt} / \pi_{usa\,jt} \cdot PPP_{cjt} \tag{3.14}$$

where y_{cjt} is real value added in US dollars of a specific year t for the industry j of country c. Y_{cjt} is a nominal value added. $\pi_{usa\,jt}$ is a value added deflator in a specific year basis, for example, 1996. $\pi_{usa\,jt}$ is used to convert the value added of each country into the constant U.S dollar values, where $\pi_{jt} = 1$ for all j when t = 1996, for example. For

$\pi_{usa\,jt}$, the GDP deflator (BEA) is used as a proxy, since $\pi_{usa\,jt}$ by manufacturing branch is not available.

PPP_{cjt} is the purchasing power parity for converting the value added in terms of the domestic currency into U.S dollar values by manufacturing branch. For PPP_{cjt}, the expenditure PPPs of International Comparisons Project (ICP PPPs: OECD) are taken as proxies for the manufacturing branch. As shown in ***Table 3.1***, the ICP PPPs are given for the main expenditure categories such as "Individual Consumption By Households", "Food, Beverages and Tobacco" and so on. It should be noted that there are big differences between classification of the expenditure ICP PPPs and that of the International Standard Industry Classification (ISIC). For this reason, GDP PPPs from ICP PPPs (OECD) were used as proxies for the ISIC manufacturing branches.

Instead of applying the GDP PPPs, it is possible to apply the PPPs of a specific expenditure category for a specific branch of the manufacturing sector. This dissertation adjusts the category differences by taking consideration of classification relevance, even though this adjustment can't avoid the fundamental index problems, of which ICP PPPs are distorted by including taxes and imported goods. By doing this adjustment, any big difference of ICP PPPs between industries within one country could be less. For example, GDP PPPs of Sweden at 1996 was 9.68 to U.S. dollar as shown in the table. The expenditure PPP of "Food, Beverages and Tobacco", however, reads 11.68, while the PPP for "Machinery and Equipment" was 8.65. If applied by the overall GDP PPPs for conversion, the value added of the industry (Food, Beverages and Tobacco) is 20 per cent over valued, while the value added (Machinery and Equipment) is 11 per cent less valued in conversion.

Table 3.1: 1996 Expenditure PPPs on GDP in National Currencies Per Us Dollar (United States = 1.00)

Division of Expenditure	Austria	Belgium	Finland	France	Germany	Italy	Neth'land
Individual Consumption By Households	14.1	38.2	6.37	6.93	2.06	1606	2.09
Food, Beverages And Tobacco	14.8	42.3	7.68	7.34	2.05	2049	2.13
Clothing And Footwear	18.0	59.9	9.34	10.13	2.75	2380	2.71
Gross Rent, Fuel And Power	12.4	39.1	5.74	7.39	2.37	1201	2.32
Household Equipment And Operation	14.5	40.8	6.11	7.24	2.13	1971	2.17
Medical And Health Care	11.2	26.3	4.69	4.56	1.51	1125	1.36
Transport And Communication	17.1	42.5	7.39	7.48	2.16	1865	2.50
Education, Recreation And Culture	13.6	35.9	5.62	6.40	1.93	1578	1.82
Miscellaneous Goods And Services	16.1	40.0	7.37	8.10	2.25	1808	2.42
Net Purchases Abroad	10.6	31.0	4.59	5.12	1.50	1544	1.69
Collective Consumption By Government	11.8	31.5	4.58	5.67	1.98	1382	1.73
Gross Fixed Capital Formation	13.2	35.8	5.13	6.00	2.05	1598	2.12
Construction	13.9	37.8	4.32	5.87	2.17	1516	2.35
Machinery And Equipment	12.3	33.1	6.29	6.16	1.88	1722	1.88
Increase In Stocks	14.5	41.0	7.37	7.14	2.06	1922	2.18
Balance Of Exports And Imports	10.6	31.0	4.59	5.12	1.50	1544	1.69
Gross Domestic Product	13.6	36.8	5.89	6.57	2.03	1583	2.04

(~continued)

Division of Expenditure	Spain	Sweden	U.K	Norway	Japan	Canada	U.S.A.
Individual Consumption By Households	126	10.25	0.67	9.83	175	1.20	1.0
Food, Beverages And Tobacco	140	11.68	0.85	13.49	255	1.42	1.0
Clothing And Footwear	198	12.49	0.85	11.59	222	1.86	1.0
Gross Rent, Fuel And Power	103	10.11	0.58	7.66	211	1.27	1.0
Household Equipment And Operation	158	10.43	0.69	9.42	244	1.23	1.0
Medical And Health Care	101	7.87	0.43	7.78	83	0.77	1.0
Transport And Communication	152	11.15	0.84	11.82	148	1.40	1.0
Education, Recreation And Culture	121	9.22	0.60	8.65	141	1.15	1.0
Miscellaneous Goods And Services	136	11.65	0.79	11.60	206	1.08	1.0
Net Purchases Abroad	127	6.71	0.64	6.46	109	1.36	1.0
Collective Consumption By Government	98	8.00	0.51	7.42	132	1.26	1.0
Gross Fixed Capital Formation	130	9.22	0.62	8.22	158	1.08	1.0
Construction	129	9.84	0.55	8.38	169	0.95	1.0
Machinery And Equipment	131	8.65	0.72	8.01	142	1.27	1.0
Increase In Stocks	144	10.69	0.77	10.73	195	1.30	1.0
Balance Of Exports And Imports	127	6.71	0.64	6.46	109	1.36	1.0
Gross Domestic Product	124	9.68	0.64	9.11	166	1.19	1.0

Data Sources: 1996 PPPs and Real Expenditures, OECD 1999.

The nominal value added comes from STAN OECD (2002) on a country basis. It should be noted that STAN OECD 2002 provides the data on value added as the Euro currency basis for European countries such as Austria, Belgium, Finland, France and Netherlands. OECD ICP, however, does not provide PPPs based on the Euro currency for these countries. In more detail, ICP PPPs are accounted based on its own domestic currencies before being unified into the Euro currency, while STAN OECD is accounted on the basis of the Euro currency.

Table 3.2: Irrevocable Conversion Rates (OECD)

Country	Own Currency	Conversion Rate
Austria	*Schilling*	13.76030
Belgium	*Franc*	40.33990
Finland	*Markka*	5.94573
France	*French Franc*	6.559570
Germany	*Deutsche Mark*	1.955830
Greece	*Drachma*	340.75000
Italy	*Italian Lira*	1936.2700
Netherlands	*Netherlands Guilder*	2.203710
Spain	*Spanish Peseta*	166.38600

Data Source: Statistic Brief, OECD Feb 2002.

Therefore, the new conversion factors should be taken into consideration for converting the value added of each country into U.S. dollar value. As conversion factors between its own domestic currencies and the Euro currency, the dissertation uses the Irrevocable Conversion Rates (OECD) as reported at ***Table. 3.2***, which were used when

OECD converted the value added in domestic currency for those countries into the value added in the Euro currency.

Furthermore, a time series of PPP_{cjt} is necessary, because the dissertation derives TFPs over time. The time series of PPP_{cjt} during this period are obtained by extrapolating Ward (1985), ICP OECD (1987), ICP OECD (1992), ICP OECD (1995) and ICP OECD (1999), combined with the Real Expenditure PPPs (OECD, 2002).

3.3.2 Capital Stock

Capital stock is defined as a distributed lag of past investment flows, namely

$$k_{cjt} = \sum (1-\delta)^{n-1} i_{cj,t-n} \qquad (3.15)$$

where k_{cjt} is real capital stock. The capital stock in year t does not include the investment of year t, but only up through year $t-1$. δ stands for the depreciation rate ($\delta < 1$). Following Harrigan (1997), this dissertation uses $\delta = 0.15$, which implies almost complete depreciation in less than 10 years. Because the data starts in 1970, this implies that the derived capital stocks of 1970 to 1979 could be flawed; they are not used.

For example, the capital stock in a specific year, say 1980, given that 1970 is the initial year, can be expressed as:

$$\begin{aligned} k_{cjt} &= i_{j,t-1} + (1-\delta)k_{j,t-1} \\ &= i_{j,t-1} + (1-\delta)i_{j,t-2} + (1-\delta)^2 i_{j,t-3} + \dots + (1-\delta)^{\tau} k_{j,1970} \end{aligned} \qquad (3.16)$$

In more compact form, the capital stock is:

$$k_{cjt} = \sum_{i=0}^{t-1} (1-\delta)^i i_{t-(1+i)} + (1-\delta)^{\tau} k_{cj1970}. \qquad (3.17)$$

The capital stock of industry j of the year 1980 can be obtained by designating the subscripts and superscripts as $\tau = t - s, t = 1980, s = 1979$ and $i = 0$ for the year 1970.

$$k_{cj1980} = \sum_{i=0}^{79} (1-\delta)^i i_{1980-(1+i)} + (1-\delta)^{1980-1970} k_{cj1970} \tag{3.18}$$

Furthermore, by defining $k_{cj1970} = i_{cj1969}$, the capital stock of a specific year, 1980 can be expressed as only past values of investment flows as following:

$$k_{cj1980} = \sum_{i=0}^{79} (1-\delta)^i i_{1980-(1+i)} + (1-\delta)^{1980-1970} i_{cj1969} \tag{3.19}$$

The real investment, i_{cjt} is constructed by the following formulation:

$$i_{cjt} = I_{cjt} / ppp_{ct}^k \cdot \pi_t \tag{3.20}$$

where I_{cjt} stands for a nominal investment of the j^{th} industry of country c at the time t. This nominal investment comes from "Gross Fixed Capital Formation (GFCF)" in the OECD STAN data. GFCF is equivalent to the investment flows of any specific industry in current own-currency values, I_{cjt}. For π_t, the implicit deflator for U.S non-residential investment is used for converting the past values of investment into a specific year value (say, 1996). ppp_{ct}^k the purchasing power parity used to convert capital formation accounts into the U.S dollar basis. These PPPs of investment goods come from the overall investment price levels from Penn Table (V6. 2001).

3.3.3 Labor Input

Labor input is constructed by using a translog aggregator on the basis of the Cobb-Douglas functional form for different kinds of labor as follows:

$$l = \prod_{k}^{L} l_k^{\alpha_k} \qquad \text{or} \qquad \log l = \sum_{k=1}^{L} \alpha_k \log l_k \tag{3.21}$$

where α_k stands for a cost share of labor type k (occupational category). Labor input, l comes from the "Total Employment, Number Engaged (EMPN)" by industry of the OECD STAN data. Employment is an imperfect indicator of labor input, since the employment represents the number engaged in work, without any consideration of working hours and the quality of labor forces. Therefore, two adjustments are made to these employment data.

First, labor input is adjusted on the basis of labor quality. In reality, however, there are no internationally comparable data on employment by industry, which provides information on hours worked and on the occupation/ skill breakdown of the labor force. The ILO[1], however, provides a breakdown of employment by occupational category as ***Table 3.3*** shows. Furthermore, the BLS (Bureau of Labor Statistics) produces data on working hours and weekly earning by the equivalent occupational categories for the U.S. labor market The aggregation of labor input, weighted by these occupational categories, is a proxy of labor quality, This process adjusts and aggregates the labor input (EMPN of OECD STAN) into $\log l$ by weighting 5 occupational categories such as Group 0/1, Group 2, Group 3, Group 5 and Group 7/8/9. The adjustment results in the quality-adjusted labor input. As a result, the aggregated $\log l$ can be considered as a translog quality-adjusted labor input. For labor input aggregation, the subscripts for country, industry and year are omitted for readability.

---

[1] Year Book of Labor Statistics, International Labor Organization (ILO).

The cost shares of labor type *k*, $\alpha_k's$ sum to unity ($\sum_{k=1}^{L}\alpha_k = 1$), implying constant returns to scale in the labor input index. Furthermore, if firms are cost-minimizers and price takers in labor markets, α_k will be the share of occupational group *k* in the total labor costs. Constructing the cost shares α_k requires data on wages, but internationally comparable wage data disaggregated by occupational group does not exist. The approach used here, following Harrigan (1997), is to assume that the occupational wage differentials in other countries are the same as in the United States.. These U.S. wage differentials come from the BLS[1].

The total labor cost is constructed by using labor earnings and weekly working hours as follows:

$$TLC = \sum_k w_k \cdot l_k \tag{3.22}$$

where TLC is a total labor cost, w_k the wage (*per hour*) of the occupational category *k*, l_k the labor input (work hours per week). Therefore, α_k is:

$$\alpha_k = w_k \cdot l_k / \sum_{j=1}^{L=5} w_j \cdot l_j \tag{3.23}$$

Second, labor input, l is converted into 40 work-hour week equivalents using average working hours of ILO by manufacturing branch. This adjustment is necessary, since the working hours are so different across countries under the same branch of the manufacturing sector and/or across industries within just one country.

[1] 1) Handbook of Labor Statistics, U.S Department of Labor Bureau of Labor Statistics, various years.
2) Employer Costs for Employee Compensation (1986-1998), U.S Department of Labor Bureau of Labor Statistics, March 2000.
3) National Compensation Survey (1997): Occupational Wages in the United States, U.S. Department of Labor, 1997.

Table 3.3: OECD Occupational Group Classification

Group No	*Occupational Description*
G 0	Total
G 0/1	Professional, Technical and Related Workers
G 2	Administrative and Managerial Workers
G 3	Clerical and Related Workers
G 4	Sales Workers
G 5	Service Workers
G 6	Agriculture, Animal Husbandry and Forestry Workers, Fishermen and Hunters
G 7/8/9	Production and Related Workers, Transport Equipment Operators and Laborers
G X	Workers Not Classifiable By Occupation

Data Source: International Standard classification of Occupations, revised edition, OECD, 1969 Geneva.

3.3.4 Labor Shares

A major difficulty in implementing a TFP comparison, based on equation (3.12) and equation (3.13), is the volatility in the labor shares *s*, which may indicate measurement error (Harrigan, 1997). Basically, labor share is constructed by an econometric approach.. Suppose that each country's value added function is a translog function form, so that the country *c*'s production function can be written as:

$$Iny_c = \alpha_{oc} + \alpha_{1c} Inl_c + \alpha_{2c} Ink_c + \alpha_{3c}(Inl_c)^2 + \alpha_{4c}(Ink_c)^2 + \alpha_{5c}(Inl_c \cdot Ink_c) \qquad (3.24)$$

where constant returns to scale requires $\alpha_{1c} + \alpha_{2c} = 1$ and $2\alpha_{3c} + \alpha_{5c} = 2\alpha_{4c} + \alpha_{5c} = 0$. Under the assumptions on technology in the industry j and factor market behavior, the labor share in the total production cost is equal to the elasticity of output with respect to labor, so that

$$s_c \equiv \partial Iny_c / \partial Inl_c = \alpha_{1c} + 2\alpha_{3c} Inl_c + \alpha_{5c} Ink_c \qquad (3.25)$$

By one of the CRS conditions, $\alpha_{5c} = -2\alpha_{3c}$. So equation (3.26) can be expressed as:

$$s_c = \alpha_{1c} + \alpha_{5c}\ln(k_c / l_c) \tag{3.26}$$

For estimating the labor shares of each country by industry, this dissertation, following Harrigan, will employ the following model over all time periods *t*:

$$s_{ct} = \alpha + \beta\ln(k_{ct} / l_{ct}) + \varepsilon_{ct} \tag{3.27}$$

The estimated labor share is obtained by using the OLS estimators and the intensity of capital per labor, $\ln(k_{ct} / l_{ct})$ as follows:

$$\hat{s}_{ct} = \hat{\alpha} + \hat{\beta}\ln(k_{ct} / l_{ct}) \tag{3.28}$$

It should be noted that the estimated labor share, $\hat{s}_{ct}$, is not fixed, but is changing over time due to the fluctuation in the intensities of capital per labor, $\ln(k_{ct} / l_{ct})$.

Furthermore, in many cases, the estimated labor shares not reasonable, since $\hat{s}_{ct}$ are estimated to be greater than 1 or too big, even though being less than 1. For these cases, the average labor share of the rest of the industries in the corresponding country is used as a proxy for the unrealistic labor share. ***Table 3.4*** presents the labor shares by manufacturing branch, which are used for calculating the multilateral TFP indices.

Table 3.4: Estimated Labor Shares by Manufacturing Branch

Model: $s_{ct} = \alpha + \beta \ln(k_{ct} / l_{ct}) + \varepsilon_{ct}$

	Coefficient	Austria	Belgium	Canada	Finland	France	U.K
ISIC 31	$\hat{\alpha}$	0.319	0.558	0.832	0.428	0.679*	0.683
	$\hat{\beta}$	0.052	0.008	-0.057	0.032	-0.013*	-0.009
ISIC 32	$\hat{\alpha}$	0.655	0.668*	0.773*	0.711	0.679*	0.666
	$\hat{\beta}$	0.012	-0.026*	-0.031	0.006	-0.013*	0.020
ISIC 33	$\hat{\alpha}$	0.549*	0.672	0.890	0.865	0.000	0.525
	$\hat{\beta}$	0.029*	-0.019	-0.025	-0.032	0.000	0.031
ISIC 34	$\hat{\alpha}$	0.707	0.705	0.775	0.810	0.646	0.696*
	$\hat{\beta}$	-0.007	-0.012	-0.018	-0.037	0.004	0.000*
ISIC 35	$\hat{\alpha}$	0.423	0.645	0.773*	0.416	0.679*	0.698
	$\hat{\beta}$	0.033	-0.020	-0.031	0.010	-0.013*	-0.009
ISIC 36	$\hat{\alpha}$	0.424	0.762	0.559	0.752	0.679*	0.696*
	$\hat{\beta}$	0.037	-0.027	0.017	-0.027	-0.013*	0.000*
ISIC 37	$\hat{\alpha}$	0.592	0.666	0.711	0.699	0.683	0.780
	$\hat{\beta}$	0.028	0.029	0.007	-0.011	0.003	0.004
ISIC 38	$\hat{\alpha}$	0.629	0.668*	0.872	0.886	0.709	0.821
	$\hat{\beta}$	0.017	-0.026*	-0.043	-0.047	0.000	-0.027
ISIC 384	$\hat{\alpha}$	0.643	0.668*	0.773*	0.775	0.679*	0.696*
	$\hat{\beta}$	0.022	-0.082	-0.031	0.006	-0.013*	0.000*
ISIC 3	$\hat{\alpha}$	0.549*	0.668*	0.773*	0.705*	0.679*	0.696*
	$\hat{\beta}$	0.029*	-0.026*	-0.031*	-0.011*	-0.013*	0.000*

Note: 1) * indicates the averaged labor share. If $\hat{\alpha} < 0.25$ or $\hat{\alpha} > 0.9$ in any industry, the originally estimated labor shares are not taken. Instead, the proxy estimators for those industries are applied, which are obtained by averaging from the reliable estimators of other industries.

2) Estimators for ISIC 3 are averaged labor shares of its branches from each country.

3) See Appendix B.2 for raw estimates for $\hat{\alpha}$ and $\hat{\beta}$.

Table 3.4: Estimated Labor Shares by Manufacturing Branch (~Continued)

Model: $s_{ct} = \alpha + \beta \ln(k_{ct} / l_{ct}) + \varepsilon_{ct}$

	Coefficient	Italia	Korea	Netherlands	Norway	Sweden	U.S.A.
ISIC 31	$\hat{\alpha}$	0.567	0.365*	0.601	0.508	0.744*	0.651
	$\hat{\beta}$	-0.020	0.017*	-0.015	0.071	-0.032*	-0.027
ISIC 32	$\hat{\alpha}$	0.875	0.365*	0.802	0.761	0.744*	0.787*
	$\hat{\beta}$	-0.066	0.017*	-0.036	0.007	-0.032*	0.041*
ISIC 33	$\hat{\alpha}$	0.782	0.404	0.676	0.574	0.606	0.759
	$\hat{\beta}$	-0.065	0.046	-0.012	0.059	0.006	-0.032
ISIC 34	$\hat{\alpha}$	0.668*	0.393	0.676*	0.730	0.750	0.818
	$\hat{\beta}$	-0.012*	0.040	-0.049*	0.001	-0.012	-0.029
ISIC 35	$\hat{\alpha}$	0.668*	0.365*	0.436	0.557	0.762	0.865
	$\hat{\beta}$	-0.012*	0.017*	0.008	0.005	-0.033	-0.055
ISIC 36	$\hat{\alpha}$	0.671	0.365*	0.631	0.625	0.744*	0.737
	$\hat{\beta}$	-0.023	0.017*	-0.007	0.003	-0.032*	0.000
ISIC 37	$\hat{\alpha}$	0.506	0.365*	0.714	0.644*	0.786	0.856
	$\hat{\beta}$	0.016	0.017*	0.000	-0.025*	-0.014	-0.026
ISIC 38	$\hat{\alpha}$	0.736	0.365*	0.872	0.748	0.744*	0.858
	$\hat{\beta}$	-0.025	0.017*	-0.023	0.017	-0.032*	-0.025
ISIC 384	$\hat{\alpha}$	0.538	0.298	0.676*	0.644*	0.818	0.752
	$\hat{\beta}$	0.043	0.029	-0.049*	-0.025*	-0.028	0.009
ISIC 3	$\hat{\alpha}$	0.668*	0.365*	0.676*	0.644*	0.744*	0.787*
	$\hat{\beta}$	-0.012*	0.017*	-0.049*	-0.025*	-0.032*	0.041*

Note: 1) * indicates the averaged labor share. If $\hat{\alpha} < 0.25$ or $\hat{\alpha} > 0.9$ in any industry, the originally estimated labor shares are not taken. Instead, the proxy estimators for those industries are applied, which are obtained by averaging from the reliable estimators of other industries.

2) Estimators for ISIC 3 are averaged labor shares of its branches from each country.

3) See Appendix B.2 for raw estimates for $\hat{\alpha}$ and $\hat{\beta}$.

3.4 TFP Outputs and Productivity Comparison

3.4.1 Derivation of Multilateral TFP Index

The objectives of the dissertation are to compute the multilateral TFP index and to make multilateral comparisons for specific manufacturing branches in Table 3.5 and the manufacturing sector as a whole. The dissertation derives yearly TFP indices for 12 OECD countries, beginning in 1980.

Table 3.5 Industry Classification of Manufacturing Sector

	ISIC Rev.3	ISIC 1968
Manufacturing Sector	15-37	
1. Food Products, Beverages and Tobacco	15-16	31
2. Textiles, Textile Products, Leather and Footwear	17-19	32
3. Wood And Products Of Wood and Cork	20	33
4. Pulp, Paper, Paper Products, Printing and Publishing	21-22	34
5. Chemical, Rubber, Plastics and Fuel Products	23-25	35
6. Other Non-Metallic Mineral Products	26	36
7. Basic Metals and Fabricated Metal Products	27-28	37
8. Machinery and Equipment	29-33	38 Except. 384
9. Transport Equipment	34-35	384

Data Sources: STAN Data, OECD 2002.

The countries consist of nine European countries - Austria, Belgium, England, Finland, France, Italy, Netherlands, Norway and Sweden, and three other OECD countries - Canada, United States and Korea. For computing the TFP index, the dissertation uses panel data on value added, gross fixed capital formulation, employment and labor compensation for OECD countries during 1970-1998. Specific manufacturing branches are identified by the 2-digit or 3-digit ISIC industry under the manufacturing sector.

In this dissertation, a country's TFP is expressed in two different ways. The first is to express a country's TFP to the U.S productivity of each year. This expression of TFP is:

$$TFP^j_{x\,usa} = \frac{y^j_x}{y^j_{usa}} \left(\frac{\bar{l}^j}{l^j_x}\right)^{\sigma_x} \left(\frac{\bar{k}^j}{k_x}\right)^{1-\sigma_x} \left(\frac{l^j_{usa}}{\bar{l}^j}\right)^{\sigma_{usa}} \left(\frac{k_{usa}}{\bar{k}^j}\right)^{1-\sigma_{usa}} \tag{3.12}$$

The second is to express a country's TFP relative to the 1990 U.S. TFP. To this end, the dissertation uses the TFP index (3.13), reformulated as,

$$TFP^j_{x\,usa.1990} = \frac{y^j_x}{y^j_{usa.1990}} \left(\frac{\bar{l}^j}{l^j_x}\right)^{\sigma_x} \left(\frac{\bar{k}^j}{k_x}\right)^{1-\sigma_x} \left(\frac{l^j_{usa.1990}}{\bar{l}^j}\right)^{\sigma_{usa}} \left(\frac{k_{usa.1990}}{\bar{k}^j}\right)^{1-\sigma_{usa}} \tag{3.12`}$$

The multilateral TFP index for the manufacturing sector as a whole is:

$$TFP_{x\,usa} = \left[\prod_{j=1}^{N} \left(\frac{y_{xj}}{\bar{y}_j}\right)^{\rho_{xj}} \left(\frac{\bar{y}_j}{y_{usaj}}\right)^{\rho_{usa\,j}}\right] \left(\frac{\bar{l}}{l_x}\right)^{\sigma_x} \left(\frac{\bar{k}}{k_x}\right)^{1-\sigma_x} \left(\frac{l_{usa}}{\bar{l}}\right)^{\sigma_{usa}} \left(\frac{k_{usa}}{\bar{k}}\right)^{1-\sigma_{usa}} \tag{3.13}$$

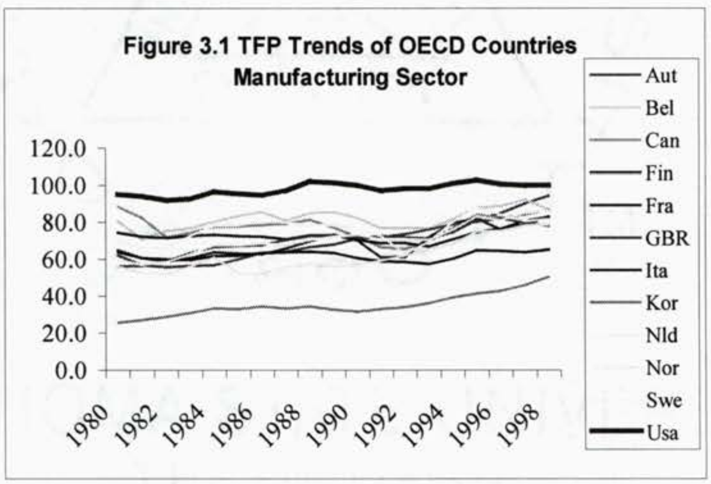
$$TFP_{x\,usa.1990} = \left[\prod_{j=1}^{N} \left(\frac{y_{xj}}{\bar{y}_j}\right)^{\rho_{xj}} \left(\frac{\bar{y}_j}{y_{usaj.1990}}\right)^{\rho_{usa\,j}}\right] \left(\frac{\bar{l}}{l_x}\right)^{\sigma_x} \left(\frac{\bar{k}}{k_x}\right)^{1-\sigma_x} \cdot \left(\frac{l_{usa.1990}}{\bar{l}}\right)^{\sigma_{usa}} \left(\frac{k_{usa.1990}}{\bar{k}}\right)^{1-\sigma_{usa}} \tag{3.13`}$$

While equation (3.12) and equation (3.12)` have no weighting process, the indices of equation (3.13) and equation (3.13)` weights the manufacturing sector by using the sectoral revenue shares. The revenue shares are expressed by sectoral outputs relative to the mean of outputs of every sector. These indices express the output index relative to an index of total capital and labor used in all sectors, where inputs are weighted using cost shares.

3.4.2 Productivity Comparison

The TFP indices in the upper sections of ***Table 3.6 - Table 3.15*** give the TFP levels of any country relative to United States (US) productivity, which are expressed as 100.0 in 1990. The TFP indices in the bottom sections stand for a country's productivity relative to the U.S.A TFP in each year.

Table 3.6 - Table 3.15 show that the United States was the highest productivity country during 1980s and 1990s in most industries among the countries compared. In particular, as ***Graph 3.1* shows**, the United States was most productive country in the manufacturing sector as a whole.



For example, the U.S TFP in 1980 registered 95.2 relative to 100 in 1990. In 1980, Canada, in the second position in TFP, was 93.3 percent of the U.S level, U.K 59.1 percent, Norway 58.8 percent and Korea 26.9 percent, respectively. In brief, the leading position of the United States in the manufacturing sector persisted over time, although the TFP gaps of the followers such as Austria, United Kingdom and Sweden decreased over

Table 3.6: Total Factor Productivity (TFP)
ISIC 3:Manufacturing Sector

YEAR	Aut	Bel	Can	Fin	Fra	U.K	Ita	Kor	Nld	Nor	Swe	U.S.A
TFP is expressed relative to a base of U.S.A in 1990 =100.												
1980	62.2	80.7	88.4	64.9	74.4	56.2	63.9	25.6	59.3	56.0	70.5	95.2
1981	56.9	70.7	82.3	60.9	72.2	56.5	60.8	27.0	57.2	52.6	65.8	94.2
1982	55.8	75.5	71.9	59.1	71.5	58.8	59.9	28.8	58.6	51.8	66.5	91.9
1983	56.5	77.0	74.4	60.8	72.5	63.6	59.5	31.0	62.9	56.3	72.7	92.7
1984	56.8	80.3	77.7	63.9	73.2	66.5	61.7	33.3	67.7	60.9	78.4	96.6
1985	60.0	83.6	78.0	63.3	72.8	67.4	62.1	32.9	67.8	52.8	78.6	95.4
1986	63.6	85.7	78.5	62.7	72.1	67.7	63.5	34.3	68.9	52.4	80.8	94.7
1987	64.1	81.1	79.4	66.1	70.9	70.4	63.9	33.4	67.7	55.9	80.2	97.1
1988	66.8	85.1	81.3	69.8	73.0	72.5	64.4	34.5	70.7	57.1	78.7	102.1
1989	68.1	85.8	77.3	73.3	73.1	72.6	63.6	32.6	72.3	56.1	78.5	101.4
1990	71.2	82.4	71.9	70.2	70.5	71.8	60.6	31.5	73.4	57.3	76.6	100.0
1991	72.5	76.9	66.7	61.2	68.6	71.9	59.0	32.9	70.8	59.5	72.6	97.3
1992	72.0	77.0	65.7	61.6	68.9	73.6	58.7	34.0	70.9	62.2	63.2	98.1
1993	71.3	76.4	69.8	71.8	67.0	76.3	57.7	36.3	70.6	65.2	69.6	98.2
1994	74.9	81.9	77.0	79.6	70.9	78.9	60.4	39.4	76.3	68.4	80.3	101.1
1995	81.3	88.0	84.3	82.1	74.8	80.3	65.0	41.5	83.2	75.2	88.2	102.9
1996	84.9	88.9	82.3	76.3	76.5	82.2	64.6	42.8	81.2	75.3	84.2	100.8
1997	90.2	92.3	84.3	78.7	80.7	79.5	63.9	45.8	85.2	78.3	80.9	100.0
1998	94.4	87.0	86.7	83.2	82.8	78.4	65.2	50.4	86.2	78.9	81.8	100.0
TFP is expressed relative to a base of U.S.A in each year =100.												
1980	65.5	82.6	92.0	68.6	77.5	59.3	64.9	26.8	61.7	59.6	71.5	100.0
1981	60.6	73.5	86.7	65.1	75.8	60.2	62.9	28.7	60.4	56.6	68.1	100.0
1982	60.7	81.3	78.0	64.5	77.3	64.1	64.2	31.0	63.4	56.8	71.3	100.0
1983	60.9	82.4	80.1	65.7	78.1	68.8	63.2	33.1	67.4	61.1	77.3	100.0
1984	58.6	82.2	80.1	66.0	75.6	69.0	62.6	34.0	69.4	63.4	79.7	100.0
1985	62.7	86.8	81.5	66.2	76.2	70.8	64.0	34.1	70.5	55.6	81.1	100.0
1986	66.8	90.2	82.9	65.9	76.3	71.6	66.2	35.9	72.2	55.4	84.4	100.0
1987	65.7	83.1	81.8	67.8	73.3	72.6	65.1	34.0	69.3	57.7	81.8	100.0
1988	65.3	82.9	79.5	68.2	71.6	71.0	62.5	33.6	69.0	56.1	76.4	100.0
1989	67.2	84.2	76.1	72.2	72.2	71.7	62.4	32.0	71.2	55.5	76.9	100.0
1990	71.2	82.4	71.9	70.2	70.5	71.8	60.6	31.5	73.4	57.3	76.6	100.0
1991	74.4	79.5	68.7	62.9	70.6	73.8	61.0	33.9	72.9	60.9	75.2	100.0
1992	73.1	79.3	67.3	62.7	70.3	74.8	60.4	34.9	72.3	63.0	65.1	100.0
1993	72.2	78.7	71.5	73.0	68.3	77.5	59.4	37.2	71.9	66.1	71.9	100.0
1994	73.6	81.9	76.5	78.6	70.5	77.8	60.4	39.2	75.6	67.4	80.6	100.0
1995	78.5	86.6	82.4	79.9	73.2	77.8	64.1	40.6	81.1	72.7	87.4	100.0
1996	83.6	89.6	82.2	75.8	76.3	81.2	65.4	42.8	81.0	74.1	85.6	100.0
1997	89.5	94.0	84.9	79.0	81.2	79.2	65.5	46.2	85.9	77.7	83.4	100.0
1998	93.4	88.9	87.4	83.4	83.3	77.9	67.1	50.8	87.0	78.0	84.9	100.0

Note: 1) Aut: Austria, Bel: Belgium, Can: Canada, Fin: Finland, Fra: France, Ita: Italia
Kor: Korea, Nld: Netherlands, Nor: Norway, Swe: Sweden

time. The productivity levels of most countries in 1990 registered 70-80 in index number, indicating that productivity was 70-80 percent of that of the U.S.A. TFP in 1990. Norway (60.6), Italy (57.3) and Korea (31.5) were out of this range.

It should be noted that the productivity gaps have decreased during 1990-1998 period, during which the United States did not register any improvement in TFP. In 1998, the productivity of the United States was 100 in terms of the index number, exactly the same as 1990, even though the productivity showed a little improvement during 1990-1995. On the other hand, the followers were catching up with the leader (U.S.A.) in eight years since 1990. As a result, the productivity gaps were narrowed down within less than 20 percent range, except for Italy (65.2) and Korea (50.4). The diminishing trends of TFP differences imply that there exists a stable convergence in the TFP movement in the manufacturing sector over time and across countries.

The United States was also the leader in the productivity comparisons for ISIC 31 (Food Products, Beverages and Tobacco), ISIC 37 (Basic Metals and Fabricated Metal Products), ISIC 38 (Machinery and Equipment) and ISIC 384 (Transport Equipment).

Broadly speaking, these new estimates of TFPs provide clear evidences on that during the 1980s and 1990s, there existed large and persistent TFP differences across OECD countries in the manufacturing sector as a whole and in several specific industries. The TFP differences are consistent with Harrigan's (1997) statement "that there exist systematic differences across countries in industry outputs in terms of TFP." And productivity comparisons by industry present more clearly the catch-ups and the convergence of the industry productivity. In industry ISIC 31, Canada had placed the second place behind the United States during 1980-1995, but after 1995, Netherlands took over Canada for the first time. For this industry (ISIC 31), it is worthwhile to notice that the United States and Canada, the leaders, showed diminishing TFPs with a little fluctuation. The productivity levels of Finland, Norway and Sweden were 50 percent less than the 1990 U.S. level during the entire 1980-1998 period.

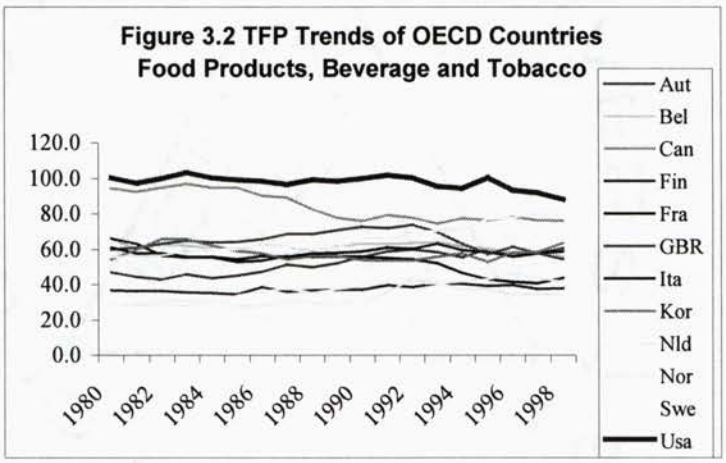


Figure 3.2 TFP Trends of OECD Countries Food Products, Beverage and Tobacco

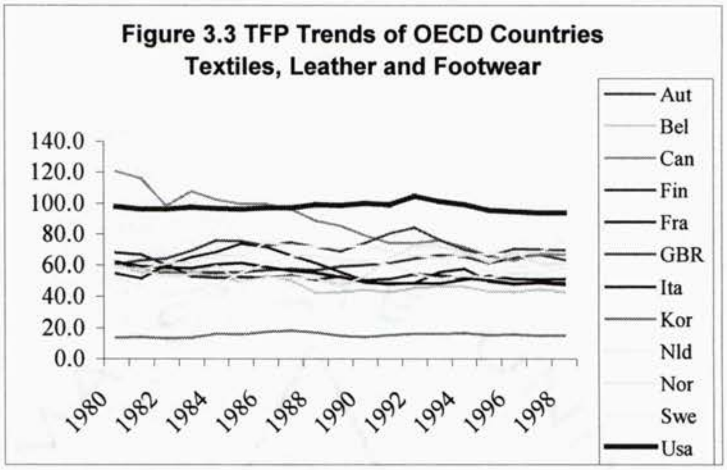
In ISIC 32 (Textiles, Textile Products, Leather and Footwear), Canada led the productivity during 1980-1985, but registered a rapid decrease, while the United States caught up with Canada and after 1987 has been the leader in that industry. In this industry, most European countries showed low productivity levels of 30-40 percent, compared to the leading countries.

Table 3.7: Total Factor Productivity (TFP)
ISIC 31: Food Products, Beverages and Tobacco

YEAR	Aut	Bel	Can	Fin	Fra	U.K	Ita	Kor	Nld	Nor	Swe	U.S.A
TFP is expressed relative to a base of U.S.A in 1990 =100.												
1980	46.8	65.9	94.2	36.8	65.9	59.8	61.0	54.4	55.9	28.2	28.5	100.4
1981	44.4	59.7	92.5	36.4	63.2	60.7	57.5	60.0	56.2	28.8	28.2	97.4
1982	43.0	62.6	94.5	36.4	56.6	63.2	57.6	65.7	56.5	30.5	27.5	99.9
1983	45.8	62.1	97.0	35.7	55.5	64.9	55.9	65.8	59.3	31.0	28.2	102.9
1984	43.7	60.4	94.7	35.3	55.7	64.0	55.6	62.0	59.7	30.8	29.2	100.0
1985	45.0	59.5	94.6	34.5	54.1	64.2	53.0	59.1	60.3	27.5	33.6	98.9
1986	47.5	62.5	90.3	38.7	56.3	65.9	53.6	57.6	62.1	28.4	36.1	98.3
1987	51.3	61.6	89.2	35.9	55.9	68.7	56.1	54.3	61.7	30.6	37.9	96.6
1988	49.8	59.5	82.6	36.7	57.5	68.8	55.8	56.3	60.0	29.9	35.1	99.3
1989	52.1	61.7	77.6	37.0	58.1	70.7	55.8	56.1	60.9	29.5	37.3	98.3
1990	55.7	63.0	76.1	37.2	58.7	72.8	55.9	53.8	66.9	30.4	39.2	100.0
1991	58.9	62.8	79.2	39.7	60.8	71.9	55.2	53.7	65.6	35.5	41.0	101.6
1992	59.9	63.5	77.9	38.7	60.3	73.7	54.3	53.4	69.7	43.2	41.0	100.2
1993	58.5	63.8	74.6	40.6	63.1	69.6	52.3	55.8	70.5	40.6	40.8	95.5
1994	55.4	61.7	77.3	40.5	59.6	63.3	46.7	57.6	70.7	37.7	41.9	94.3
1995	60.0	60.1	76.3	39.1	58.4	57.1	42.8	52.9	77.1	37.0	42.9	100.1
1996	56.2	58.1	78.1	39.5	55.8	61.1	41.5	58.1	77.8	34.4	46.3	93.4
1997	57.8	58.5	76.4	37.3	57.8	57.5	40.7	58.5	80.5	34.7	43.6	91.9
1998	60.5	55.6	75.9	37.8	58.8	54.3	43.5	63.4	80.0	34.1	41.5	88.1
TFP is expressed relative to a base of U.S.A in each year =100.												
1980	47.1	66.7	94.8	37.3	71.5	61.0	60.1	54.2	55.9	30.3	25.8	100.0
1981	45.9	62.2	95.6	38.0	69.6	63.5	58.6	61.7	57.8	31.5	26.8	100.0
1982	43.3	63.3	95.1	36.8	59.7	64.1	57.3	65.1	56.6	32.0	26.0	100.0
1983	44.7	60.8	94.6	35.0	56.1	63.8	54.0	63.4	57.6	31.2	26.1	100.0
1984	43.9	60.8	94.9	35.6	57.8	64.6	55.3	61.6	59.7	31.8	28.0	100.0
1985	45.6	60.5	95.9	35.1	56.3	65.4	53.4	59.5	61.0	28.5	32.9	100.0
1986	48.4	63.9	92.0	39.5	58.6	67.4	54.3	58.4	63.2	29.4	35.8	100.0
1987	53.2	64.0	92.4	37.3	58.8	71.5	57.9	56.0	63.9	32.1	38.4	100.0
1988	50.2	60.1	83.2	37.1	58.5	69.5	56.2	56.6	60.5	30.4	35.0	100.0
1989	53.1	62.9	79.0	37.7	59.6	72.0	56.7	57.0	62.0	30.2	37.6	100.0
1990	55.7	63.0	76.1	37.2	58.7	72.8	55.9	53.8	66.9	30.4	39.2	100.0
1991	57.8	61.7	77.9	39.0	59.3	70.6	54.4	52.9	64.5	34.7	40.7	100.0
1992	59.6	63.0	77.6	38.4	58.9	73.1	54.3	53.4	69.4	42.4	41.9	100.0
1993	60.9	66.4	78.0	42.2	64.3	72.3	54.9	58.6	73.7	41.6	44.0	100.0
1994	58.5	65.0	81.9	42.7	61.5	66.6	49.7	61.3	74.9	39.1	45.9	100.0
1995	59.5	59.5	76.0	38.7	56.2	56.4	42.9	53.1	76.9	35.9	44.7	100.0
1996	59.6	61.5	83.5	41.7	56.7	64.6	44.7	62.5	83.1	35.4	52.5	100.0
1997	62.1	62.7	82.9	40.0	59.2	61.5	44.5	63.9	87.4	36.0	50.8	100.0
1998	67.6	62.0	85.9	42.1	62.2	60.4	49.7	72.3	90.6	36.5	51.1	100.0

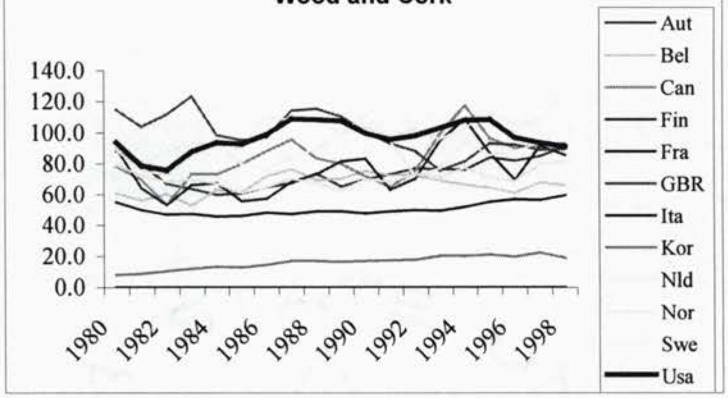
Table 3.8: Total Factor Productivity (TFP)
ISIC 32: Textiles, Textile Products, Leather and Footwear

YEAR	Aut	Bel	Can	Fin	Fra	U.K	Ita	Kor	Nld	Nor	Swe	U.S.A
TFP is expressed relative to a base of U.S.A in 1990 =100.												
1980	62.1	59.1	120.7	67.8	54.8	60.7	62.3	13.5	58.4	59.1	52.2	97.8
1981	56.2	55.3	115.8	66.9	52.0	62.9	59.3	14.0	57.3	56.5	46.6	96.1
1982	55.7	56.9	98.2	60.2	59.6	64.2	58.2	13.2	60.9	53.2	41.5	96.1
1983	55.6	55.5	107.7	53.0	65.0	69.4	58.0	13.7	62.3	54.1	43.1	97.3
1984	55.2	52.5	102.3	52.0	68.2	75.8	60.6	16.1	65.2	59.6	48.2	96.5
1985	55.3	49.9	99.2	52.4	73.7	75.5	61.4	15.8	65.5	49.6	55.1	96.1
1986	56.8	53.3	99.3	52.1	71.6	72.3	58.7	17.3	74.5	52.1	60.8	96.9
1987	57.6	50.6	96.1	53.5	66.1	74.6	56.4	18.4	72.5	52.7	65.8	96.7
1988	56.5	42.6	88.5	51.1	61.1	71.7	55.1	16.8	71.6	51.9	65.8	99.1
1989	59.0	43.2	85.3	53.1	55.6	68.6	52.6	14.9	71.8	47.1	63.5	98.6
1990	60.0	44.3	79.1	49.1	50.3	74.3	49.4	14.1	72.5	53.2	63.3	100.0
1991	61.4	43.1	74.1	48.2	51.3	80.2	48.6	15.3	69.3	64.1	60.0	99.0
1992	64.0	45.4	74.0	49.0	54.4	84.3	48.6	16.2	66.3	72.8	54.6	104.2
1993	66.3	46.6	76.0	55.5	53.5	76.3	48.4	16.1	64.5	72.0	51.3	101.0
1994	65.6	46.4	71.8	57.5	51.8	70.2	50.8	16.7	66.2	67.8	53.6	99.2
1995	61.3	43.4	66.0	49.7	50.4	65.8	53.0	15.4	67.0	61.8	52.2	95.3
1996	64.8	43.2	63.0	48.2	48.5	70.6	51.2	15.9	67.0	67.7	54.5	94.3
1997	66.9	44.6	67.1	48.9	49.1	70.1	50.8	15.1	68.1	61.0	53.7	93.7
1998	63.4	43.0	66.7	47.8	48.8	69.5	51.2	14.9	75.2	60.7	58.6	93.5
TFP is expressed relative to a base of U.S.A in each year =100.												
1980	64.4	57.8	121.9	70.7	52.2	63.0	63.2	13.9	59.9	62.5	51.4	100.0
1981	59.2	55.3	119.2	70.8	50.8	66.4	61.2	14.7	59.8	60.6	46.8	100.0
1982	58.4	57.9	101.6	63.2	60.0	67.3	60.3	13.6	63.4	56.3	42.4	100.0
1983	57.7	55.3	109.8	55.2	63.6	72.1	59.2	14.0	64.2	56.9	43.1	100.0
1984	57.8	52.8	105.2	54.7	67.4	79.4	62.4	16.6	67.8	63.2	48.7	100.0
1985	57.9	51.0	102.8	55.0	74.6	79.0	63.6	16.4	68.2	52.3	56.5	100.0
1986	59.0	54.0	102.0	54.2	71.7	75.1	60.4	17.8	77.0	54.5	61.7	100.0
1987	60.0	51.2	98.8	55.9	66.0	77.8	58.1	18.9	75.1	55.4	66.9	100.0
1988	57.4	42.3	88.9	51.9	60.2	72.7	55.5	16.9	72.3	52.9	65.6	100.0
1989	60.2	43.3	86.3	54.2	55.4	70.0	53.2	15.1	72.9	48.2	63.8	100.0
1990	60.0	44.3	79.1	49.1	50.3	74.3	49.4	14.1	72.5	53.2	63.3	100.0
1991	61.9	43.8	75.0	48.6	52.2	80.9	49.1	15.4	70.0	64.5	60.9	100.0
1992	61.3	43.9	71.1	46.9	52.7	80.6	46.7	15.5	63.6	69.5	52.7	100.0
1993	65.4	46.5	75.4	54.7	53.6	75.3	48.0	15.9	63.9	71.0	51.1	100.0
1994	65.8	47.3	72.6	57.6	53.3	70.4	51.3	16.8	66.7	67.8	54.6	100.0
1995	63.6	46.8	69.8	51.5	55.2	68.2	56.0	16.1	70.2	63.7	55.9	100.0
1996	67.5	47.8	67.6	50.1	54.9	73.6	54.8	16.6	70.8	69.9	59.8	100.0
1997	70.0	49.9	72.7	51.1	56.5	73.2	54.8	15.8	72.5	63.2	59.6	100.0
1998	66.1	48.9	72.6	49.7	57.4	72.3	55.4	15.5	80.1	62.4	65.8	100.0



In ISIC 33 (Wood and Products of Wood and Cork), the United Kingdom was the leader of the productivity during 1980-1990 over 11 countries. After 1990, Netherlands and the United States took over from United Kingdom and during the last 8 years, several countries (the United States, Sweden and Finland) were close to the frontier (Netherlands). The industry is characterized by the fact that the European countries such as Austria, Finland, Norway and Sweden were showing no big differences in the productivity levels. On the other hand, Belgium and Italy had registered no big improvements in the productivity from 1980 to 1998.

Figure 3.4 TFP Trends of OECD Countries
Wood and Cork



In ISIC 34 (Pulp, Paper Products, Printing and Publishing), the European countries took strong places in the productivity during all periods (1980-1998). United Kingdom recorded the highest TFP levels of 120 relative to the 1990 U.S. 100 level. Belgium and France and Italy were among the members of the frontier group. After 1995, the Netherlands took the first place out of the European countries. If Korea is excluded in the productivity comparisons, this industry showed the smallest range of productivity across countries.

Figure 3.5 TFP Trends of OECD Countries
Pulp, Paper and Printing

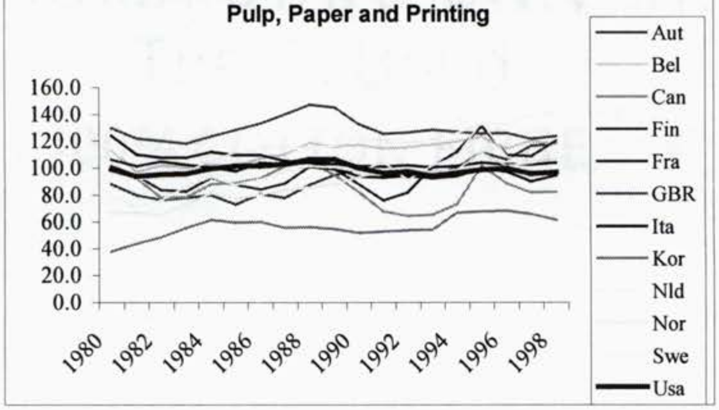


Table 3.9: Total Factor Productivity (TFP)
ISIC 33: Wood and Products of Wood and Cork

YEAR	Aut	Bel	Can	Fin	Fra	U.K	Ita	Kor	Nld	Nor	Swe	U.S.A
TFP is expressed relative to a base of U.S.A in 1990 =100.												
1980	88.2	60.9	78.3	90.4	.	114.7	55.0	7.8	90.6	79.3	89.1	93.7
1981	80.0	56.3	69.6	64.2	.	104.1	50.2	8.6	81.6	72.5	75.8	78.5
1982	67.1	60.6	53.6	53.4	.	111.7	47.0	10.3	87.2	68.3	72.5	75.6
1983	64.0	52.9	73.4	66.2	.	123.5	47.6	12.1	92.6	70.1	85.4	87.8
1984	60.1	63.4	73.3	67.5	.	98.4	46.1	13.2	92.0	67.1	92.4	93.7
1985	60.8	61.6	79.8	55.8	.	95.4	46.4	13.0	90.5	61.1	80.0	92.6
1986	65.0	71.9	88.1	57.5	.	97.3	48.4	14.4	110.7	64.8	76.5	99.1
1987	67.4	76.8	95.9	68.3	.	114.2	47.8	16.9	108.0	70.4	83.9	109.0
1988	73.6	69.6	83.6	73.4	.	115.4	49.5	17.0	108.0	67.4	89.9	108.4
1989	65.3	70.4	80.1	81.6	.	110.7	49.1	16.4	99.4	63.0	99.7	107.7
1990	70.2	75.4	72.3	83.4	.	100.5	48.0	16.8	103.4	70.0	111.5	100.0
1991	73.2	72.6	65.0	63.5	.	93.1	49.4	17.2	97.9	68.4	94.6	95.5
1992	77.0	72.6	75.4	70.6	.	88.1	50.0	17.7	102.8	73.9	72.7	98.3
1993	76.8	69.1	99.3	94.7	.	75.7	49.7	20.3	95.9	71.6	77.2	103.3
1994	76.0	66.6	117.6	108.9	.	81.7	52.3	20.4	103.2	77.5	94.2	108.2
1995	84.3	64.7	96.3	86.9	.	93.1	55.6	21.3	112.7	71.3	85.9	108.6
1996	82.2	61.4	90.3	69.6	.	92.4	57.3	19.9	105.3	68.7	88.3	97.1
1997	84.9	67.7	91.9	91.5	.	89.2	56.6	22.4	107.7	80.0	93.7	93.5
1998	91.0	66.3	93.1	85.6	.	89.4	59.7	19.0	126.7	81.0	90.3	91.2
TFP is expressed relative to a base of U.S.A in each year =100.												
1980	92.6	65.0	82.9	95.9	.	122.2	59.2	8.3	96.7	83.3	94.8	100.0
1981	98.7	71.8	87.2	80.8	.	132.1	64.9	10.7	104.0	89.8	96.0	100.0
1982	84.2	80.4	68.8	69.3	.	146.8	63.7	13.7	115.4	86.1	94.9	100.0
1983	70.8	60.3	82.3	74.7	.	140.2	55.0	13.9	105.5	77.8	96.7	100.0
1984	63.3	67.6	77.6	71.7	.	104.9	49.5	14.1	98.2	70.8	98.3	100.0
1985	64.7	66.5	85.5	60.0	.	102.9	50.5	14.1	97.7	65.2	86.2	100.0
1986	65.1	72.6	88.5	57.9	.	98.1	49.0	14.5	111.8	65.0	77.1	100.0
1987	62.0	70.4	88.1	62.8	.	104.8	43.8	15.5	99.1	64.8	77.0	100.0
1988	68.2	64.2	77.3	67.9	.	106.6	45.5	15.6	99.7	62.5	83.0	100.0
1989	60.9	65.3	74.5	75.9	.	102.8	45.5	15.2	92.3	58.8	92.7	100.0
1990	70.2	75.4	72.3	83.4	.	100.5	48.0	16.8	103.4	70.0	111.5	100.0
1991	75.7	76.1	67.6	66.2	.	97.3	52.0	18.0	102.5	70.7	98.8	100.0
1992	77.8	73.9	76.5	71.6	.	89.6	51.1	18.0	104.6	74.7	73.8	100.0
1993	74.6	66.9	96.4	91.8	.	73.3	48.0	19.6	92.9	69.6	74.8	100.0
1994	71.1	61.5	109.3	101.0	.	75.6	48.1	18.8	95.4	72.4	87.3	100.0
1995	78.0	59.6	89.0	80.2	.	85.8	51.1	19.6	103.8	66.0	79.2	100.0
1996	84.0	63.3	92.6	71.5	.	95.1	59.2	20.5	108.4	70.2	90.8	100.0
1997	89.2	72.5	97.3	97.2	.	95.1	61.0	24.0	115.0	84.2	99.8	100.0
1998	98.2	72.8	101.2	93.4	.	97.8	65.9	20.8	138.8	87.6	98.7	100.0

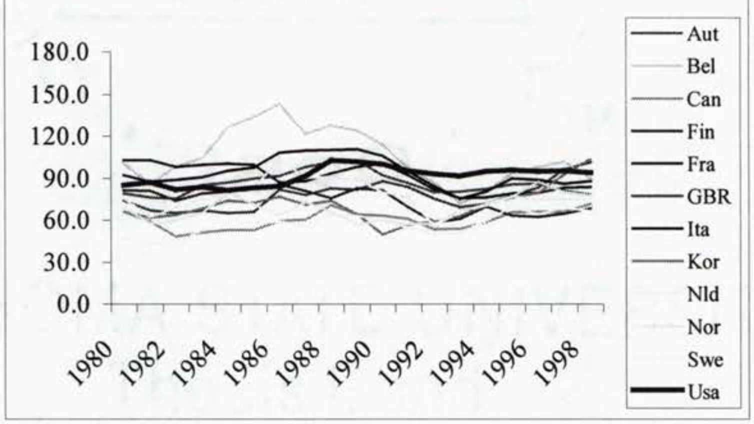
Note: 1) TFP is not available for ISIC 33 of France, since OECD STAN (2002) does not provide data on Gross Fixed Capital Formation.

Table 3.10: Total Factor Productivity (TFP)
ISIC 34: Pulp, Paper, Paper Products, Printing and Publishing

YEAR	Aut	Bel	Can	Fin	Fra	U.K	Ita	Kor	Nld	Nor	Swe	U.S.A
TFP is expressed relative to a base of U.S.A in 1990 =100.												
1980	87.9	113.1	100.0	101.3	105.9	129.7	124.1	37.8	96.1	66.1	78.4	98.9
1981	79.8	97.1	92.2	94.2	101.4	122.0	110.0	43.5	91.9	67.1	71.5	93.9
1982	76.3	102.1	78.0	83.4	104.7	120.2	107.9	48.3	92.8	64.9	75.8	95.3
1983	77.6	100.5	78.2	82.8	102.3	118.0	107.8	55.9	96.4	73.0	86.5	95.6
1984	79.6	102.3	87.9	92.9	100.2	123.7	111.8	61.4	106.0	81.0	93.2	99.4
1985	73.3	100.8	88.8	87.4	97.7	128.5	109.5	59.5	111.3	77.2	87.3	101.3
1986	80.7	107.3	92.4	84.3	103.9	133.1	109.6	59.9	115.0	80.1	91.1	101.5
1987	77.7	110.1	101.4	88.2	102.9	139.6	105.4	55.9	114.4	83.4	96.8	103.0
1988	87.5	118.5	104.2	101.0	104.4	146.9	103.8	56.4	114.4	85.4	101.4	106.4
1989	94.9	115.7	94.5	98.8	102.7	144.9	99.9	55.0	116.9	87.6	100.2	106.0
1990	98.4	117.0	82.4	87.8	101.5	132.6	93.9	51.9	122.5	93.2	96.9	100.0
1991	95.9	114.1	67.7	75.8	100.8	125.4	92.7	52.8	120.2	96.9	104.3	96.1
1992	92.6	115.1	64.5	81.5	101.9	126.4	94.1	53.8	118.2	98.4	90.7	97.0
1993	95.6	117.3	65.1	101.0	100.7	128.3	92.2	54.5	120.4	97.1	101.7	93.8
1994	100.1	119.8	73.0	112.1	101.2	126.6	93.8	66.6	125.9	98.5	107.9	96.3
1995	111.6	123.1	101.1	131.2	103.9	125.2	99.4	68.0	132.1	111.3	134.6	98.6
1996	106.1	114.4	88.4	109.5	102.3	126.0	97.0	68.2	133.2	101.3	108.2	99.5
1997	116.2	120.2	81.8	108.8	102.5	121.3	89.8	66.0	138.4	103.6	104.4	95.6
1998	117.6	117.2	82.0	120.1	103.6	123.4	94.0	61.7	141.0	106.7	112.2	96.8
TFP is expressed relative to a base of U.S.A in each year =100.												
1980	88.7	113.4	101.2	101.2	106.7	126.8	116.9	38.0	95.7	67.7	79.7	100.0
1981	84.9	102.8	98.3	99.4	107.7	126.5	110.5	46.1	96.7	72.4	76.5	100.0
1982	80.0	106.5	81.9	86.8	109.6	123.4	107.9	49.5	96.4	68.7	79.8	100.0
1983	81.2	104.7	81.9	85.9	106.8	120.8	107.6	57.1	99.9	77.1	90.8	100.0
1984	80.0	102.4	88.6	92.6	100.6	121.5	106.9	60.3	105.6	82.3	94.1	100.0
1985	72.3	99.1	87.8	85.7	96.3	124.3	103.5	57.7	109.0	76.9	86.4	100.0
1986	79.5	105.4	91.1	82.6	102.3	129.1	104.4	58.2	112.6	79.4	90.0	100.0
1987	75.5	106.7	98.5	85.3	99.8	133.8	99.6	53.7	110.5	81.3	94.2	100.0
1988	82.3	111.2	98.0	94.6	98.1	136.6	95.3	52.6	107.2	80.6	95.5	100.0
1989	89.5	109.0	89.2	92.9	96.8	135.7	92.8	51.6	109.9	82.9	94.6	100.0
1990	98.4	117.0	82.4	87.8	101.5	132.6	93.9	51.9	122.5	93.2	96.9	100.0
1991	99.7	118.9	70.4	79.1	104.8	131.5	98.2	55.2	125.5	100.4	108.3	100.0
1992	95.4	118.9	66.4	84.4	105.0	132.0	99.8	55.9	122.4	100.9	93.3	100.0
1993	101.9	125.3	69.4	108.3	107.3	138.7	101.3	58.5	129.0	102.9	108.2	100.0
1994	103.9	124.5	75.7	117.0	105.1	133.1	100.1	69.7	131.3	101.7	111.8	100.0
1995	113.0	124.9	102.4	133.7	105.3	128.8	104.0	69.5	134.6	112.2	136.1	100.0
1996	106.5	115.1	88.7	110.8	102.7	128.7	101.1	69.1	134.6	101.1	108.3	100.0
1997	121.3	125.9	85.4	114.6	107.2	129.3	97.8	69.6	145.7	107.5	108.7	100.0
1998	121.3	121.3	84.5	125.1	107.0	130.4	102.3	64.2	146.8	109.1	115.3	100.0

In ISIC 35 (Chemical, Rubber, Plastics and Fuel Products), Belgium and France were co-leaders in the productivity in term of TFP. The position of Belgium remained untouched until 1990, while France lost its position as a leader after 1985. Italy took over the place of France and showed the high productivity of the industry until 1990. After 1990, there were several catch-ups in productivity among some countries such as Belgium, the United State and Austria. In particular, it is worth noting the catch-up of Korea, which recorded a rapid increase in the productivity from 66.0 in 1980 to 103.7 in 1998. Even though Korea took the first place just one time at 1998, Korea's growing trend of the productivity overwhelmed other countries under comparison.

Figure 3.6 TFP Trends of OECD Countries
Chemical and Fuel Products



In ISIC 36 (Other Non-Metallic Mineral Products), Canada and the United States showed relatively high TFPs over last 18 years. Although two countries experienced decreasing productivity in the early 1990s, the overall productivity levels were approximately 20 percent higher than in the European countries, excluding the United Kingdom and Italy. Italy recorded stagnating productivity after 1988, while United Kingdom registered the lowest productivity level before 1992, excepting Korea.

Table 3.11: Total Factor Productivity (TFP)
ISIC 35: Chemical, Rubber, Plastics and Fuel Products

TFP is expressed relative to a base of U.S.A in 1990 =100.

YEAR	Aut	Bel	Can	Fin	Fra	U.K	Ita	Kor	Nld	Nor	Swe	U.S.A
1980	74.0	100.7	66.0	81.5	103.0	79.2	92.0	66.0	47.5	69.1	75.4	84.9
1981	67.0	85.5	59.3	80.8	103.0	76.4	87.5	61.9	43.8	57.6	62.4	86.9
1982	65.1	98.4	48.3	73.8	98.1	75.6	88.6	63.7	43.7	59.8	68.8	81.6
1983	66.9	104.3	51.2	78.9	99.5	85.0	90.7	68.3	53.2	65.3	74.7	83.5
1984	65.1	126.5	52.9	80.5	100.6	86.9	95.2	73.7	59.6	80.1	77.6	81.5
1985	66.2	134.1	53.2	83.4	99.4	89.8	97.8	72.5	58.3	71.2	82.9	83.3
1986	81.9	143.1	59.4	85.6	87.0	91.8	108.3	76.9	59.2	63.5	104.0	84.3
1987	77.9	121.8	60.4	81.1	87.7	98.2	109.8	71.2	55.8	73.2	90.4	91.5
1988	82.8	128.1	70.6	75.9	93.4	101.4	110.1	73.9	64.7	66.0	91.4	102.8
1989	81.8	124.2	64.3	82.9	98.1	102.6	110.9	64.0	63.4	56.6	89.1	101.8
1990	88.0	114.2	63.4	81.4	100.4	92.3	105.9	50.0	59.4	60.0	80.2	100.0
1991	83.8	97.0	60.9	69.2	91.9	86.7	94.7	56.9	54.9	57.2	76.5	95.3
1992	75.4	86.4	53.4	58.8	81.9	80.2	84.4	59.0	51.0	57.4	56.0	93.1
1993	69.5	72.3	53.9	60.7	75.8	80.5	75.4	63.0	51.3	66.4	66.0	91.8
1994	71.6	80.2	58.5	69.9	76.0	82.4	80.7	71.1	59.4	70.3	71.6	94.7
1995	77.8	93.7	65.6	63.1	79.0	85.4	89.8	76.3	69.6	76.6	77.3	96.0
1996	83.4	98.3	66.2	62.2	79.5	86.0	88.7	79.6	64.0	87.4	74.4	94.7
1997	96.3	101.9	66.1	64.6	83.1	80.9	86.1	92.5	68.7	79.8	74.7	95.3
1998	101.4	89.6	71.7	68.3	83.5	78.1	87.8	103.7	66.5	77.6	75.3	93.8

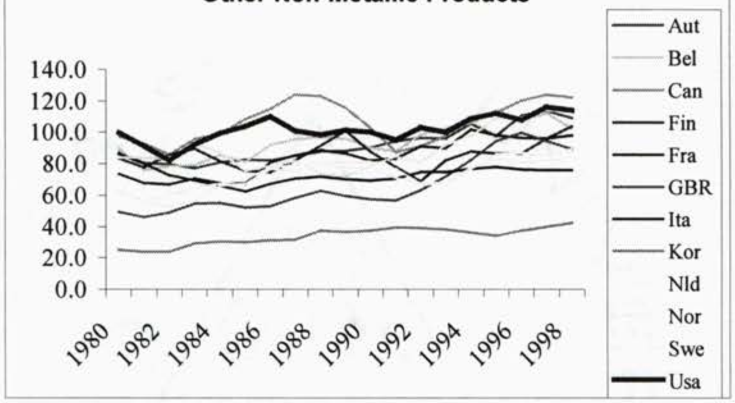
TFP is expressed relative to a base of U.S.A in each year =100.

YEAR	Aut	Bel	Can	Fin	Fra	U.K	Ita	Kor	Nld	Nor	Swe	U.S.A
1980	87.4	118.2	76.7	95.4	127.3	93.8	105.1	77.5	55.6	81.8	89.0	100.0
1981	77.3	98.2	67.5	92.6	123.1	88.4	98.5	71.3	50.2	66.5	72.0	100.0
1982	79.8	120.5	59.0	90.4	120.8	92.6	108.2	77.9	53.5	73.3	84.3	100.0
1983	80.1	124.9	61.3	94.5	118.7	101.8	108.9	81.8	63.7	78.1	89.5	100.0
1984	79.9	155.2	64.7	98.6	124.8	106.8	116.1	90.3	73.0	98.4	95.3	100.0
1985	79.5	160.9	63.7	100.0	120.1	107.8	116.9	86.9	69.9	85.5	99.5	100.0
1986	97.1	169.7	70.3	101.5	103.5	108.9	128.2	91.1	70.2	75.3	123.4	100.0
1987	85.3	133.1	65.7	88.5	97.4	107.5	118.8	77.5	61.0	80.1	98.9	100.0
1988	80.7	124.5	68.4	73.8	92.6	98.9	106.0	71.6	62.9	64.4	89.0	100.0
1989	80.5	121.9	62.9	81.4	98.1	101.0	107.9	62.7	62.2	55.7	87.6	100.0
1990	88.0	114.2	63.4	81.4	100.4	92.3	105.9	50.0	59.4	60.0	80.2	100.0
1991	87.7	101.8	64.3	72.6	94.1	90.6	100.6	59.9	57.6	59.8	80.1	100.0
1992	80.6	92.8	58.0	63.3	83.9	85.5	92.9	63.8	54.9	61.3	60.0	100.0
1993	75.1	78.8	59.7	66.5	77.1	86.8	85.3	69.2	56.0	71.8	71.7	100.0
1994	74.8	84.7	63.0	74.2	74.0	86.0	89.1	75.7	62.9	73.7	75.3	100.0
1995	80.2	97.5	69.8	66.2	74.7	87.7	98.4	80.2	72.7	79.1	80.1	100.0
1996	87.0	103.6	71.8	66.2	74.8	89.2	99.6	85.0	67.8	91.0	78.1	100.0
1997	99.7	106.8	71.6	68.6	76.2	83.2	97.1	98.1	72.4	82.6	77.8	100.0
1998	106.2	95.2	79.1	73.6	76.7	81.3	101.2	111.3	71.2	81.4	79.6	100.0

Table 3.12: Total Factor Productivity (TFP)
ISIC 36: Other Non-Metallic Mineral Products

YEAR	Aut	Bel	Can	Fin	Fra	U.K	Ita	Kor	Nld	Nor	Swe	U.S.A
TFP is expressed relative to a base of U.S.A in 1990 =100.												
1980	87.0	89.7	97.4	83.2	73.5	49.2	86.3	25.1	62.7	83.6	62.4	99.6
1981	80.4	76.1	92.6	77.7	67.9	46.0	80.2	23.7	55.3	83.9	56.2	91.2
1982	79.5	78.5	85.7	85.8	67.0	49.0	72.6	23.7	53.0	83.3	60.5	82.3
1983	77.4	79.4	95.5	89.3	70.5	54.7	69.2	29.1	56.3	92.8	64.7	92.4
1984	80.7	85.2	98.9	81.9	67.6	55.1	66.3	30.5	66.0	87.6	67.5	99.5
1985	82.4	81.5	108.2	75.5	67.2	52.3	62.5	30.1	67.3	75.5	70.4	104.0
1986	82.0	92.1	115.0	74.8	81.0	53.1	67.3	31.0	76.7	78.9	77.6	110.2
1987	85.1	95.7	124.1	82.3	85.6	58.3	70.5	31.4	75.4	81.7	79.4	101.2
1988	87.7	96.7	123.1	91.5	88.8	62.9	71.8	37.2	79.4	73.9	81.0	98.5
1989	88.2	96.3	115.6	100.9	86.5	59.6	70.3	36.4	77.8	71.8	81.3	101.4
1990	90.5	90.2	102.8	87.8	82.0	57.5	69.2	37.4	77.5	79.0	81.5	100.0
1991	94.5	87.8	87.6	77.9	83.3	56.7	70.5	39.4	71.0	84.7	76.8	95.2
1992	96.4	98.4	91.1	69.0	91.1	63.1	74.9	39.1	67.6	81.0	67.3	102.9
1993	96.3	102.7	97.8	82.2	89.8	71.9	74.9	38.0	67.8	92.0	66.9	100.2
1994	105.3	106.1	107.2	88.0	102.0	82.5	76.6	36.2	77.5	97.5	76.9	108.9
1995	97.6	114.1	112.7	86.8	98.3	94.5	78.2	34.0	83.1	108.9	86.1	112.2
1996	110.9	108.0	120.2	86.6	96.6	99.7	76.4	37.5	80.5	109.7	87.0	108.0
1997	113.8	112.3	124.1	96.1	96.1	94.6	76.1	39.9	82.3	114.2	85.7	116.4
1998	109.1	102.5	122.2	104.0	98.1	89.6	76.1	42.5	84.2	113.6	89.6	114.1
TFP is expressed relative to a base of U.S.A in each year =100.												
1980	86.2	88.9	96.9	82.4	69.3	48.1	84.9	24.8	62.0	83.1	58.4	100.0
1981	87.7	83.0	101.1	84.7	72.5	49.9	87.3	25.8	60.2	91.6	59.8	100.0
1982	96.9	95.6	104.3	104.6	82.7	59.9	88.7	28.9	64.6	101.5	74.7	100.0
1983	83.7	85.9	103.4	96.7	76.1	59.1	74.9	31.5	61.0	100.5	69.9	100.0
1984	80.5	85.0	98.9	81.6	65.4	54.6	65.8	30.4	65.7	87.5	65.3	100.0
1985	78.8	77.8	103.5	72.1	62.6	49.6	59.5	28.8	64.2	72.3	65.6	100.0
1986	74.2	83.2	104.1	67.6	71.9	47.7	60.6	28.0	69.2	71.4	68.8	100.0
1987	84.0	94.5	122.5	81.2	84.0	57.4	69.5	31.0	74.4	80.7	77.9	100.0
1988	88.9	97.9	124.7	92.6	88.9	63.4	72.5	37.6	80.3	74.9	81.0	100.0
1989	86.8	94.6	113.7	99.1	83.9	58.4	69.0	35.8	76.4	70.6	78.8	100.0
1990	90.5	90.2	102.8	87.8	82.0	57.5	69.2	37.4	77.5	79.0	81.5	100.0
1991	99.8	92.8	92.4	82.3	89.8	60.2	74.6	41.5	75.0	89.3	82.8	100.0
1992	94.0	96.1	88.8	67.4	90.5	62.0	73.3	38.1	66.1	79.0	67.0	100.0
1993	96.3	102.7	97.8	82.3	90.7	72.2	75.0	38.0	67.9	92.0	67.7	100.0
1994	96.7	97.3	98.4	80.7	93.2	75.7	70.3	33.3	71.1	89.5	70.3	100.0
1995	86.9	101.7	100.4	77.3	87.4	84.1	69.7	30.3	74.1	97.0	76.6	100.0
1996	102.7	100.0	111.3	80.2	89.7	92.4	70.8	34.8	74.6	101.7	80.8	100.0
1997	98.3	97.2	107.1	83.2	85.4	82.4	66.0	34.3	71.3	98.6	76.2	100.0
1998	96.7	91.2	108.1	92.5	92.7	81.0	68.2	37.4	75.0	100.6	84.6	100.0

Figure 3.7 TFP Trends of OECD Countries Other Non-Metallic Products



In ISIC 37 (Basic Metals and Fabricated Metal Products), the United States was the only frontier country during 1980-1995. U.S. productivity in this industry fluctuated over time, but registered big gaps over the next countries such as Canada and Belgium. In particular, the productivities of European countries (Austria, United Kingdom, Finland, Netherlands and Sweden) were low in the same period. After 1995, however, Belgium took the frontier position of the industry and other European countries also succeeded in narrowing down the productivity difference from the frontier country. The United Kingdom especially improved its position in this industry productivity from 35.7 in 1980 to 80.1 in 1995. As of the end of 1998, Belgium, Canada and the United States are the frontier countries in this industry.

Table 3.13: Total Factor Productivity (TFP)
ISIC 37: Basic Metals and Fabricated Metal Products

TFP is expressed relative to a base of U.S.A in 1990 =100.

YEAR	Aut	Bel	Can	Fin	Fra	U.K	Ita	Kor	Nld	Nor	Swe	U.S.A
1980	68.1	80.9	92.8	63.1	69.2	35.7	58.9	20.4	53.2	81.3	68.9	108.8
1981	59.2	72.5	86.5	54.4	64.5	38.0	54.5	24.7	50.5	63.6	59.8	108.8
1982	63.4	72.6	72.4	58.8	66.6	39.8	52.2	25.9	54.7	56.3	60.7	97.9
1983	62.2	76.8	77.7	63.0	68.0	46.2	49.2	29.1	55.0	72.5	67.1	90.5
1984	62.0	77.7	84.4	62.7	68.5	47.9	50.7	30.1	62.7	86.6	75.7	98.0
1985	70.8	83.7	86.7	60.8	67.7	48.1	48.8	31.7	64.5	64.8	75.8	94.9
1986	69.2	84.1	82.4	61.9	69.5	48.4	50.5	37.0	61.9	58.4	78.6	96.7
1987	68.6	79.7	86.5	63.6	67.5	47.0	51.4	40.0	61.5	60.6	78.8	96.2
1988	73.4	98.0	89.9	71.8	74.0	50.6	55.5	38.0	67.6	78.2	77.1	104.0
1989	75.7	106.6	83.9	80.0	77.5	49.7	55.6	38.6	73.4	80.9	77.1	103.2
1990	74.6	95.9	74.8	68.0	70.2	52.4	52.3	36.2	71.6	65.1	79.9	100.0
1991	74.4	86.0	68.9	65.4	70.1	56.8	52.9	36.2	70.1	64.4	76.1	94.9
1992	71.5	91.9	69.5	72.4	71.6	63.1	55.4	34.7	67.6	65.9	65.3	94.7
1993	68.3	87.7	74.6	88.4	68.9	65.6	57.5	36.7	63.8	73.8	73.3	97.2
1994	74.0	97.1	84.5	97.2	76.4	71.5	63.0	36.3	70.3	81.5	88.9	102.4
1995	85.1	108.6	95.9	99.7	85.4	80.1	72.0	39.8	77.7	97.4	101.1	104.7
1996	89.4	103.7	96.7	89.9	86.1	80.0	70.7	38.8	72.2	90.8	94.6	102.9
1997	93.4	111.5	100.8	87.1	89.3	77.4	68.6	41.2	76.3	93.5	90.5	101.4
1998	97.7	107.3	102.9	82.7	92.9	78.8	68.3	39.8	76.8	97.3	91.5	101.7

TFP is expressed relative to a base of U.S.A in each year =100.

YEAR	Aut	Bel	Can	Fin	Fra	U.K	Ita	Kor	Nld	Nor	Swe	U.S.A
1980	62.6	75.2	85.4	57.4	63.4	33.0	53.3	18.7	48.8	74.6	63.4	100.0
1981	54.4	67.2	79.5	49.6	59.1	35.1	49.5	22.7	46.3	58.3	54.9	100.0
1982	64.8	74.0	73.9	60.2	68.1	40.6	53.5	26.6	55.9	57.5	62.0	100.0
1983	68.7	84.6	85.8	69.8	75.2	51.0	54.6	32.3	60.8	80.1	74.2	100.0
1984	63.2	79.5	86.1	63.9	69.9	49.0	51.5	30.5	64.0	88.3	77.3	100.0
1985	74.6	88.4	91.4	64.0	71.3	50.7	51.3	33.2	67.9	68.3	79.9	100.0
1986	71.6	87.0	85.3	64.0	71.9	50.1	52.2	38.2	64.0	60.4	81.3	100.0
1987	71.3	82.9	90.0	66.0	70.2	48.9	53.3	41.4	63.9	62.9	81.9	100.0
1988	70.6	94.6	86.5	68.9	71.1	48.7	53.2	36.3	65.0	75.2	74.1	100.0
1989	73.4	103.6	81.4	77.4	75.1	48.3	53.7	37.2	71.1	78.4	74.7	100.0
1990	74.6	95.9	74.8	68.0	70.2	52.4	52.3	36.2	71.6	65.1	79.9	100.0
1991	78.3	90.1	72.5	69.1	73.8	59.7	56.0	38.4	73.9	67.8	80.2	100.0
1992	75.4	96.4	73.2	76.7	75.7	66.5	58.8	37.0	71.4	69.6	68.9	100.0
1993	70.2	89.7	76.6	91.2	70.8	67.3	59.5	38.0	65.6	75.9	75.4	100.0
1994	72.2	94.6	82.5	95.0	74.6	69.7	61.6	35.6	68.7	79.6	86.8	100.0
1995	81.2	103.3	91.5	95.5	81.6	76.3	69.1	38.2	74.2	93.1	96.5	100.0
1996	86.8	100.1	93.9	87.8	83.7	77.5	69.2	38.0	70.2	88.4	92.0	100.0
1997	92.0	109.0	99.3	86.4	88.2	76.0	68.2	41.0	75.3	92.4	89.2	100.0
1998	95.9	104.3	100.9	81.9	91.5	77.0	67.9	39.6	75.6	95.9	90.0	100.0

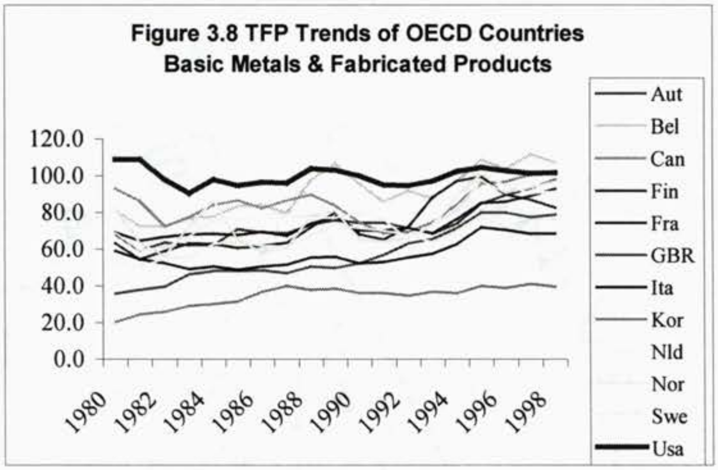
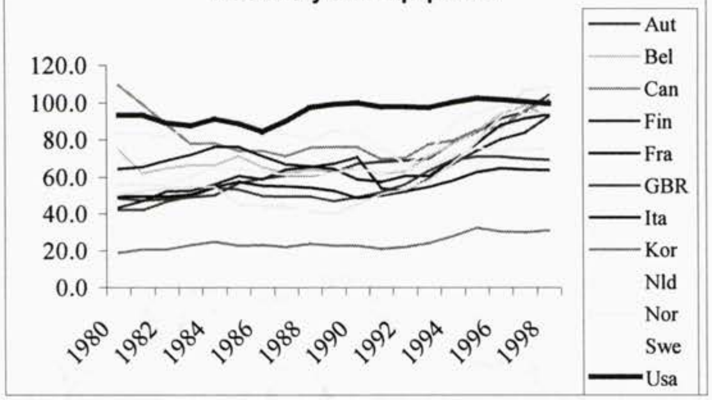


Figure 3.8 TFP Trends of OECD Countries
Basic Metals & Fabricated Products

In ISIC 38 (Machinery and Equipment), the United Sates had the highest TFP in the industry. In 1980, Canada placed the first place in the productivity, but lost its frontier position after 1982. The productivity of the United States in past 18 years fluctuated from 93.1 in 1980 to 84.7 in 1986 to 100.0 in 1990. The productivities of European countries in this industry were far behind the U.S. level. For example, the TFP numbers of Austria, Finland and United Kingdom were less than or around 50.0, when the United States was at higher than 90.0. In late 1990s, the productivity differences narrowed greatly down and Norway finally took over the frontier place of the industry productivity in 1997. Moreover, most European countries (except United Kingdom, Italy and Netherlands) approached t within 10 %-bound of the U.S. TFP level at 1997 and 1998.

Figure 3.9 TFP Trends of OECD Countries Machinery and Equipment



In ISIC 384 (Transport Equipment), the United States was clearly leading in industry productivity. The U.S. TFP in 1980 registered 89.0 relative to 100 in 1990. After 1981, its productivity started to improve and reached to 128.0 in 1984. The United States experienced a stagnant period, but rebounded after 1990 and kept its frontier place. Belgium and Sweden represented the frontiers among the European countries, while United Kingdom, Finland and France were not productive relative to other European countries.

Figure 3.10 TFP Trends of OECD Countries Transport Equipment

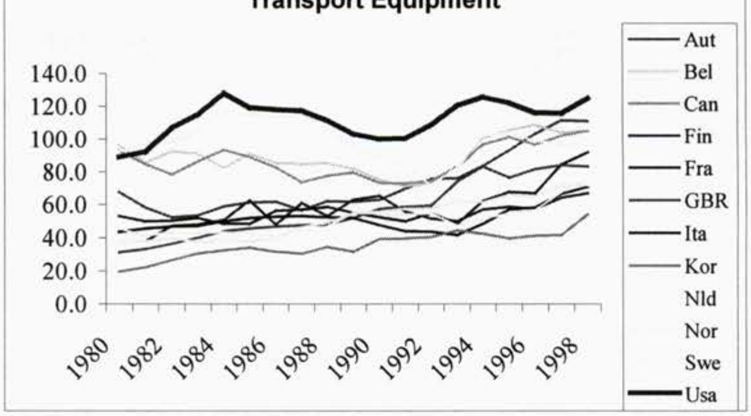


Table 3.14: Total Factor Productivity (TFP)
ISIC 38: Machinery and Equipment

TFP is expressed relative to a base of U.S.A in 1990 =100.

YEAR	Aut	Bel	Can	Fin	Fra	U.K	Ita	Kor	Nld	Nor	Swe	U.S.A
1980	48.2	74.6	109.2	43.5	64.2	42.3	49.3	18.9	55.0	50.3	83.7	93.1
1981	47.5	62.0	99.1	46.9	65.3	42.2	49.3	20.7	55.1	52.3	83.7	93.3
1982	48.1	64.6	88.3	52.1	68.8	46.7	49.2	20.5	56.0	53.8	81.3	89.0
1983	48.9	66.4	77.9	52.4	71.9	49.5	50.5	23.0	60.6	54.8	87.4	87.7
1984	50.2	66.4	78.3	56.1	76.0	54.4	54.6	24.6	65.0	54.8	91.9	91.2
1985	56.6	71.2	73.9	60.4	76.3	53.3	57.5	22.4	63.5	45.1	91.2	88.8
1986	59.3	65.3	74.2	58.7	71.3	49.7	55.3	23.1	62.8	44.7	86.9	84.7
1987	60.8	61.9	71.5	64.1	66.9	49.2	54.8	22.1	61.4	43.7	83.4	90.1
1988	60.9	64.1	75.8	65.4	65.9	49.2	54.3	23.6	61.1	41.3	80.1	97.5
1989	62.5	63.6	76.1	67.1	64.4	46.8	52.5	22.5	62.1	40.1	85.0	99.1
1990	67.0	64.2	76.3	70.5	58.9	49.1	48.7	22.6	64.4	45.3	84.4	100.0
1991	68.3	62.1	69.6	53.8	57.3	51.9	50.1	20.9	62.3	50.6	76.5	97.6
1992	68.7	63.2	70.1	52.6	60.6	56.2	52.3	21.8	64.4	53.1	66.9	97.6
1993	69.9	70.9	77.4	58.7	60.5	63.3	54.6	23.9	65.3	58.2	72.7	97.3
1994	78.2	77.8	79.5	67.3	68.7	69.1	58.2	27.8	71.8	67.4	88.2	100.1
1995	84.3	84.6	85.1	74.2	77.9	70.8	62.7	32.3	75.7	78.8	94.4	102.1
1996	91.6	93.9	86.9	80.3	88.1	70.9	64.9	30.4	74.2	92.4	98.8	101.6
1997	95.0	98.4	95.8	84.0	91.6	69.9	64.0	30.0	75.3	106.7	94.0	100.4
1998	104.0	92.4	101.2	92.4	93.6	69.2	63.6	30.8	75.8	108.3	94.8	99.5

TFP is expressed relative to a base of U.S.A in each year =100.

YEAR	Aut	Bel	Can	Fin	Fra	U.K	Ita	Kor	Nld	Nor	Swe	U.S.A
1980	51.0	72.3	115.3	45.6	68.2	44.7	50.9	19.9	59.6	55.8	84.1	100.0
1981	50.4	61.1	104.8	49.2	69.4	44.7	51.2	21.8	59.5	57.7	85.0	100.0
1982	53.7	68.7	98.2	57.7	76.9	52.1	54.2	22.4	63.3	61.5	88.2	100.0
1983	55.4	72.5	88.1	59.0	81.7	56.1	56.7	25.7	69.3	63.4	96.9	100.0
1984	54.7	69.1	85.0	60.7	83.0	59.2	58.7	26.3	71.7	61.1	97.4	100.0
1985	63.4	77.0	82.6	67.3	85.6	59.7	63.7	24.8	71.8	51.4	100.1	100.0
1986	69.9	75.5	87.2	69.0	84.1	58.6	64.7	27.0	74.3	53.1	101.2	100.0
1987	67.4	67.6	79.1	70.8	74.2	54.5	60.5	24.3	68.2	48.7	91.5	100.0
1988	62.4	64.6	77.4	66.8	67.5	50.4	55.4	24.0	62.8	42.6	81.2	100.0
1989	63.0	63.4	76.5	67.4	65.0	47.2	52.7	22.6	62.8	40.6	85.1	100.0
1990	67.0	64.2	76.3	70.5	58.9	49.1	48.7	22.6	64.4	45.3	84.4	100.0
1991	70.0	64.4	71.6	55.4	58.7	53.3	51.5	21.5	63.7	51.7	79.0	100.0
1992	70.5	66.2	72.2	54.2	62.1	57.7	54.1	22.5	65.8	54.0	69.5	100.0
1993	71.8	74.8	80.0	60.7	62.2	65.2	56.6	24.7	66.9	59.4	76.0	100.0
1994	78.1	79.6	79.8	67.6	68.7	69.2	58.6	27.9	71.6	66.9	89.5	100.0
1995	82.6	85.2	83.8	73.1	76.4	69.6	62.1	31.9	73.9	76.6	94.1	100.0
1996	90.3	95.9	86.2	79.7	86.9	70.2	64.7	30.1	72.8	90.0	99.5	100.0
1997	94.9	102.8	96.4	84.7	91.4	70.1	64.9	30.1	74.7	104.8	96.5	100.0
1998	104.9	98.8	103.1	94.3	94.4	70.2	65.3	31.1	75.8	107.0	99.0	100.0

Table 3.15: Total Factor Productivity (TFP)
ISIC 384: Transport Equipment

YEAR	Aut	Bel	Can	Fin	Fra	U.K	Ita	Kor	Nld	Nor	Swe	U.S.A
TFP is expressed relative to a base of U.S.A in 1990 =100.												
1980	67.5	96.0	92.3	37.4	53.0	31.4	43.5	19.5	45.8	37.3	91.9	89.0
1981	58.3	85.4	84.5	38.1	49.8	33.5	45.8	22.2	41.4	38.2	97.3	91.9
1982	52.4	92.5	78.4	47.4	50.5	36.4	46.7	26.9	43.7	39.8	98.9	106.9
1983	53.5	90.7	86.1	47.8	51.7	40.3	47.1	30.8	43.3	37.9	105.1	114.9
1984	59.1	82.3	93.3	50.7	48.3	43.9	50.0	32.5	43.4	38.9	116.5	128.0
1985	61.3	90.6	89.0	62.6	48.5	45.7	51.9	34.2	42.6	37.8	116.0	119.1
1986	61.8	85.3	82.5	48.0	56.2	47.0	52.6	31.8	40.6	39.5	113.2	117.9
1987	56.7	84.4	73.4	60.8	57.2	47.6	53.1	30.8	43.6	46.3	114.7	117.1
1988	62.0	84.8	77.3	53.1	58.6	48.1	52.3	34.7	46.8	49.2	106.5	111.4
1989	61.7	81.8	79.3	63.1	54.9	51.7	52.0	32.0	54.9	54.8	95.3	103.0
1990	62.7	75.2	73.3	65.4	52.5	57.4	47.4	39.3	54.5	55.8	88.4	100.0
1991	69.6	71.3	72.8	55.7	50.0	58.4	43.9	39.8	53.9	57.4	83.8	100.4
1992	75.6	72.6	74.1	51.6	54.8	59.3	43.7	40.6	54.5	57.5	71.6	108.4
1993	75.9	82.6	83.0	50.1	48.3	73.9	41.6	44.6	47.4	62.2	82.7	120.3
1994	83.3	100.3	96.2	56.9	62.2	82.9	48.6	42.6	51.5	61.4	101.8	125.6
1995	92.8	105.6	101.3	58.8	67.6	76.5	57.2	39.6	54.9	66.0	103.6	122.0
1996	102.9	108.5	96.4	57.3	66.8	81.3	58.3	41.4	56.5	64.7	98.6	116.0
1997	111.3	103.8	102.0	64.1	84.0	83.9	66.6	41.6	67.6	71.8	96.6	115.6
1998	110.9	105.0	105.1	66.9	91.7	83.0	70.8	54.1	76.2	71.6	96.5	124.8
TFP is expressed relative to a base of U.S.A in each year =100.												
1980	75.1	98.1	99.2	42.1	54.8	36.8	48.3	21.7	49.6	40.0	100.5	100.0
1981	63.0	86.3	88.6	41.5	50.8	37.7	49.4	24.0	43.8	40.1	103.7	100.0
1982	48.9	84.7	72.5	44.3	46.4	34.4	43.6	24.8	40.6	36.8	92.0	100.0
1983	46.4	76.6	73.8	41.6	43.9	35.5	40.9	26.3	37.2	32.6	90.8	100.0
1984	46.0	60.2	70.7	39.6	35.8	35.3	38.9	24.2	33.1	29.5	89.6	100.0
1985	51.2	71.2	72.5	52.6	38.7	39.4	43.4	27.4	35.0	30.8	95.8	100.0
1986	52.2	68.9	68.4	40.7	45.9	40.7	44.5	26.1	33.8	32.9	94.8	100.0
1987	48.4	70.4	62.0	52.0	47.9	41.0	45.3	25.9	36.9	39.1	97.4	100.0
1988	55.6	75.2	69.0	47.7	52.1	43.4	47.0	30.9	41.9	44.0	95.3	100.0
1989	59.8	78.1	76.3	61.2	52.5	50.6	50.5	30.7	53.0	52.8	92.1	100.0
1990	62.7	75.2	73.3	65.4	52.5	57.4	47.4	39.3	54.5	55.8	88.4	100.0
1991	69.5	72.9	73.5	55.5	50.9	57.5	43.8	40.3	54.2	57.8	84.1	100.0
1992	69.9	70.0	69.9	47.6	52.4	53.6	40.4	38.4	51.0	53.9	66.8	100.0
1993	63.3	72.7	70.9	41.6	42.0	59.9	34.7	38.3	40.1	52.8	69.7	100.0
1994	66.5	84.6	78.7	45.3	51.7	64.3	38.7	35.1	41.8	49.9	82.2	100.0
1995	76.3	92.2	85.6	48.2	58.2	60.9	47.0	33.6	45.9	55.4	86.3	100.0
1996	89.1	101.0	86.3	49.4	61.1	67.7	50.4	37.2	49.9	57.4	86.7	100.0
1997	96.8	97.1	91.7	55.4	77.2	70.0	57.7	37.6	59.9	64.0	85.3	100.0
1998	89.3	92.2	88.1	53.6	78.8	63.7	56.9	45.5	62.8	59.3	79.1	100.0

3.5 Conclusion of Productivity Comparison

One important purpose of this dissertation is to confirm Harrigan's statement "that there exist systematic differences across countries in industry outputs in terms of TFP that cannot be explained by differences in factor endowments". Computed by applying the CCD multilateral TFP index, the TFP differences by industry provide several indications in understanding a country's relative productivity level. One remarkable finding shows that there were large productivity differences across countries, but that these differences narrowed over 1980s and 1990s. Especially, the gaps of the industry productivity have fluctuated yearly, but diminished in a very stable manner in the long run. In conclusion, the dissertation confirms that there are substantial technology differences (TFP differences) in the manufacturing sector as a whole and in 2-digit ISIC manufacturing branches among 12 OECD countries. In the manufacturing sector as a whole, the Unites States was the only leader among 12 OECD countries, while in the 2-digit ISIC industries, several countries such as Canada, Belgium and United Kingdom were leading in the industry productivity. Productivity catch-up and convergence were clear over 1980-1998 in every industry.

However, to explain fully the catch-ups and convergence across countries and over time, a specific framework is required. At the same time, what factors are attributed to the systematic differences in TFP should be answered. The questions are equivalent to asking what factors except differences in factor endowments determine the TFP growth rate, as asked by Harrigan (1997). Therefore, the dissertation investigates these topics in the next chapter.

Chapter IV

ANALYSIS ON CATCH-UP AND CONVERGENCE OF INDUSTRY PRODUCTIVITY

4.1 Introduction

Much neoclassical economic theory assumes that the production function or technology is known by all of the relevant economic agents. Thus, one firm can do what another does, and across countries an industry can access a common production function. If the production function or technology is changing, however, it is reasonable to assume that the change originates in a particular firm and in a particular country. In country studies, a typical assumption is that other firms in the industry in the same country quickly adopt the new technology. The diffusion of the technology change across countries, however, may be hindered by numerous factors.

At the aggregate level, some empirical literature shows that technology, broadly speaking, is not perfectly and quickly mobile across countries. Islam (1995) postulated and tested the proposition that total factor productivity may differ across countries because of differences in Hicks-neutral productivity. In a slightly earlier paper, Benhabib and Spiegel (1994) tested whether TFP differences across countries could be accounted for in a leader-follower framework in which one country is at the productivity frontier and follower countries are in a catch up process. Maddison (1991) in a non-econometric study has shown the power of such a framework in explaining long-run capitalistic development. Adkins, Moomaw, and Savvides (2002) examine the extent to which economic freedom influences the distance a country is from the world production frontier, using a stochastic frontier methodology.

Recent studies by Bernard and Jones (1996) and by Harrigan (1997) concentrate on cross-country comparisons of productivity in sectors of the aggregate economy. Bernard and Jones estimate convergence in broad sectors of the aggregate economy, e. g. agriculture, mining, and manufacturing. Although they found evidence of convergence for other sectors of the economy, they did not find evidence of convergence in manufacturing. Harrigan's study of 2-digit ISIC manufacturing industries did not test for convergence; he showed, however, that TFP for manufacturing industries differs across OECD countries.

The purpose in this chapter is to analyze convergence in TFP for manufacturing industries in 12 OECD countries, using newly available data. The dissertation uses the Malmquist multilateral TFP index that is described in chapter 3. Productivity (TFP) indexes are calculated using data from the OECD's STAN 2002 database, making this dissertation one of the first to use the industry database on the new industrial classification codes.

This chapter of the dissertation makes two contributions. First, it provides new findings of cross-country productivity convergence, using the newly available data. Unlike some earlier studies, it finds productivity convergence in the manufacturing sector. Second, in addition to examining convergence, the dissertation also estimates the effect of economic freedom on productivity levels and on productivity growth. It finds that a country's economic institutions, as measured by an index of economic freedom, are associated with both the level and growth of TFP at the level of the manufacturing sector. For manufacturing branches, the results support a positive effect of economic freedom on productivity levels, but the results for productivity growth are weaker.

4.2 TFP Convergence in Manufacturing Branches across Countries

There are two distinct definitions of convergence; β-convergence and σ-convergence (Barro and Sala-i-Martin, 1991, 1992). Productivity convergence across countries can be analyzed based on two questions: (1) Do countries with relatively high initial levels of TFP grow relatively slowly (β-convergence)? and (2) Is there a reduction over time in the cross-sectional variance of TFP (σ-convergence)? If the idea of a common technology for an industry across countries - at least in the long run - is to have any validity, both types of convergence would seem to be necessary.

4.2.1 β-Convergence

Following Barnard and Jones (1996), assume that productivity (TFP) for a manufacturing branch in country i, $A_{i,t}$, is:

$$\ln A_{i,t} = \gamma_i + \lambda \ln G_{i,t} + \ln A_{i,t-1} + \ln \varepsilon_{i,t} \tag{4.1}$$

where, $A_{i,t}$ is the total factor productivity ($TFP_{i,t}$) of country i, γ_i is the asymptotic rate of TFP growth, λ is the catch-up parameter and $\varepsilon_{i,t}$ is a manufacturing branch and country specific error term. The productivity gap, $G_{i,t}$ is the previous period's productivity in country i, branch j relative to that in base country b, the country with the highest TFP:

$$\ln G_{i,t} = -\ln \hat{A}_{i,t-1} \tag{4.2}$$

where the hat over the variable represents the ratio of country $i's$ to country b's variable:

$$\hat{A}_{i,t} = \frac{A_{i,t}}{A_{b,t}} \tag{4.3}$$

$\hat{A}_{i,t}$ is the productivity gap and can be expressed as a function of past values of its variable by using equation (4.1), (4.2) and (4.3) as follows:

$$\ln \hat{A}_{i,t} = \ln A_{i,t} - \ln A_{b,t}$$

$$= (\gamma_i - \gamma_b) + \lambda(\ln G_{i,t} - \ln G_{b,t}) + (\ln A_{i,t-1} - \ln A_{b,t-1}) + (\ln \varepsilon_{i,t} - \ln \varepsilon_{b,t})$$

$$= (\gamma_i - \gamma_b) + \lambda \ln G_{i,t} + \ln \hat{A}_{i,t-1} + \ln \hat{\varepsilon}_{i,t}$$

$$= (\gamma_i - \gamma_b) + (1 - \lambda)\ln \hat{A}_{i,t-1} + \ln \hat{\varepsilon}_{i,t} \tag{4.4}$$

since $\ln G_{b,t} = 0$ because $\ln G_{b,t} = -\ln \hat{A}_{b,t-1} = -\ln(A_{b,t-1} / A_{b,t-1})$ and $\ln \hat{A}_{i,t-1} = \ln A_{i,t-1} - \ln A_{b,t-1}$ by an analogy of equation (4.3). This formulation of productivity catch-up, $\ln \hat{A}_{i,t}$, says that the productivity gap between country i and the base country b is a function of the lagged gap ($\ln \hat{A}_{i,t-1}$) in the same productivity measure. Still following Bernard and Jones (1996), if $\lambda > 0$ and ($\gamma_i = \gamma_b$), then productivity differentials result in a higher growth rate for the country with lower productivity. Alternatively, if $\lambda = 0$, TFP levels will grow at different rates over time with no convergence.

Bernard and Jones also formulate the average growth rate, $\overline{A}_i$, relative to the base country b between time 0 and T as:

$$\overline{A}_i = -\frac{1-(1-\lambda)^T}{T}\ln \hat{A}_{i,0} + \frac{1}{T}\sum_{s=0}^{T}(1-\lambda)^{T-s}(\gamma_i - \gamma_b + \ln \hat{\varepsilon}_{i,s}) \tag{4.5}$$

A regression of the long run average growth rate on the initial productivity gap tests convergence, with a negative coefficient on the initial gap required for convergence. The intuition of this is straightforward. As the productivity in the low productivity country increases relative to that of the leader country, the catch-up opportunities available to the low productivity country decrease.

The dissertation uses this specification for the cross-sectional catch-up analysis of TFPs, which were calculated by using the Malmquist multilateral index theory, as developed by Caves et al. The dissertation presents the estimates for the cross-section convergence of TFP for the 9 manufacturing branches and the manufacturing sector as a whole for 12 OECD countries over the period 1980-1998. These countries and industries are those included in the new STAN database for which the data necessary to calculate TFP could be obtained. The 12 countries are Austria, Belgium, Canada, Finland, France, U.K, Italy, Korea, Netherlands, Norway, Sweden and United States. The 9 manufacturing branches represent the industries under the two-digit category industry of ISIC such as ISIC 31, ISIC 32 and so on.

Following Bernard and Jones (1996), the estimating model is specified as:

$$\Delta \ln(TFP_i) = \alpha + \beta \ln(TFP_i^{1980}) + \varepsilon_i \tag{4.6}$$

where $\Delta \ln(TFP_i)$ is the growth rate of TFP of country over 1980-1998, which can be expressed as $\ln(TFP_i^{1998} / TFP_i^{1980})^{1/T} = (1/T)(\ln TFP_i^{1998} - \ln TFP_i^{1980})$. The level of productivity (TFP_i) is derived by using the calculated Malmquist TFP index (TFP_i^m), such that $TFP_i = TFP_i^m / TFP_{usa}^m$. The speed of convergence, λ, is calculated from

$$\beta = -\frac{1-(1-\lambda)^T}{T} \tag{4.7}$$

Table 4.1 presents the estimated results on β-convergence for TFP. For each manufacturing branch, the growth rate of TFP is regressed on its initial level of TFP with a constant, producing an estimate of β. The implied convergence speed, λ, is calculated using the equation 4.7. This convergence speed is the rate at which TFP level is converging to the productivity leader (for example, USA), which may itself be growing over time. As shown in ***Table 4.1***, all branches of manufacturing and the manufacturing sector exhibit convergence. The estimated negative coefficient of the initial productivity gap is significant at the 10 percent level using a one-tail test for *Food, Beverages and Tobacco,* at 5 percent for *Basic Metals and Fabricated Metal Products*, and at 1 percent for the remaining 7 industries.

Table 4.1: TFP Convergence Regressions by Manufacturing Branch

	β	SE	t	λ	R^2
Manufacturing Sector	-0.02370	0.00981	-2.42	0.0304	0.42
Food, Beverages and Tobacco	-0.01427	0.00827	-1.73	0.0164	0.27
Textiles, Leather and Footwear Products	-0.01968	0.00351	-5.61	0.0240	0.80
Wood and Products of Wood and Cork	-0.03199	0.00995	-3.22	0.0465	0.56
Pulp, Paper and Printing & Publishing	-0.04044	0.01386	-2.92	0.0698	0.52
Chemical, Rubber, Plastics and Fuel Products	-0.01950	0.00673	-2.90	0.0237	0.51
Other Non-Metallic Mineral Products	-0.02303	0.00513	-4.49	0.0293	0.72
Basic Metals and Fabricated Metal Products	-0.02094	0.00966	-2.17	0.0259	0.37
Machinery and Equipment	-0.03355	0.00385	-8.72	0.0501	0.90
Transport Equipment	-0.03073	0.00610	-5.04	0.0438	0.76

Notes: 1) This regression is based on TFP indices of 12 OECD countries by industry.

2) $\beta's$ and $\lambda's$ are estimated and calculated from the following equations:

Estimation Model: $\Delta \ln(TFP_i) = \alpha + \beta \ln(TFP_i^{1980}) + \varepsilon_i$

$$\text{where, } \Delta \ln(TFP_i) = \frac{1}{T}(\ln TFP_i^{1998} - \ln TFP_i^{1980})$$

$$\text{Speed of Convergence: } \beta = -\frac{1-(1-\lambda)^T}{T}$$

The convergence rates for the manufacturing branches vary from 2.37 percent in *Chemical, Rubber, Plastics and Fuel Products* to 6.98 percent in *Pulp, Paper and Printing & Publishing.* Just as there is substantial variation in the convergence rates, the R^2 s for the convergence regressions vary substantially—from 0.27 for *Food, Beverages and Tobacco* to 0.90 for *Machinery and Equipment*.

4.2.2 σ - Convergence

One way to examine the data for σ -convergence is to study the time trend of the standard deviation of the productivity relatives. A declining standard deviation indicates that the TFPs for various countries are getting closer. ***Figure 4.1*** presents the cross-sectional standard deviations of log TFP over time by manufacturing branch. The manufacturing sector exhibits a reduction in this standard deviation over time. It falls in the early 1980s, is flat until about 1990, when it again resumes its fall. In all the manufacturing branches, the standard deviations are lower at the end than at the beginning of the period.

Several patterns exist, however, within this generalization. *Chemicals* and *Pulp and Paper* both have extended periods (about a decade) of rising standard deviation, and the pattern for textiles is uneven. The remaining industries have declining trends with some interruption. The pattern would seem to be consistent with the idea that σ -convergence is relatively strong, but it is interrupted by country-industry specific shocks.

The existence of relative strong evidence in support of β convergence and the indications of σ -convergence support the idea that technology transfer occurs between and among countries. The remainder of this chapter presents some preliminary estimates of the effects of economic freedom on relative productivity levels and growth.

Figure 4.1 Standard Deviation of (Log) TFP by Manufacturing Branch

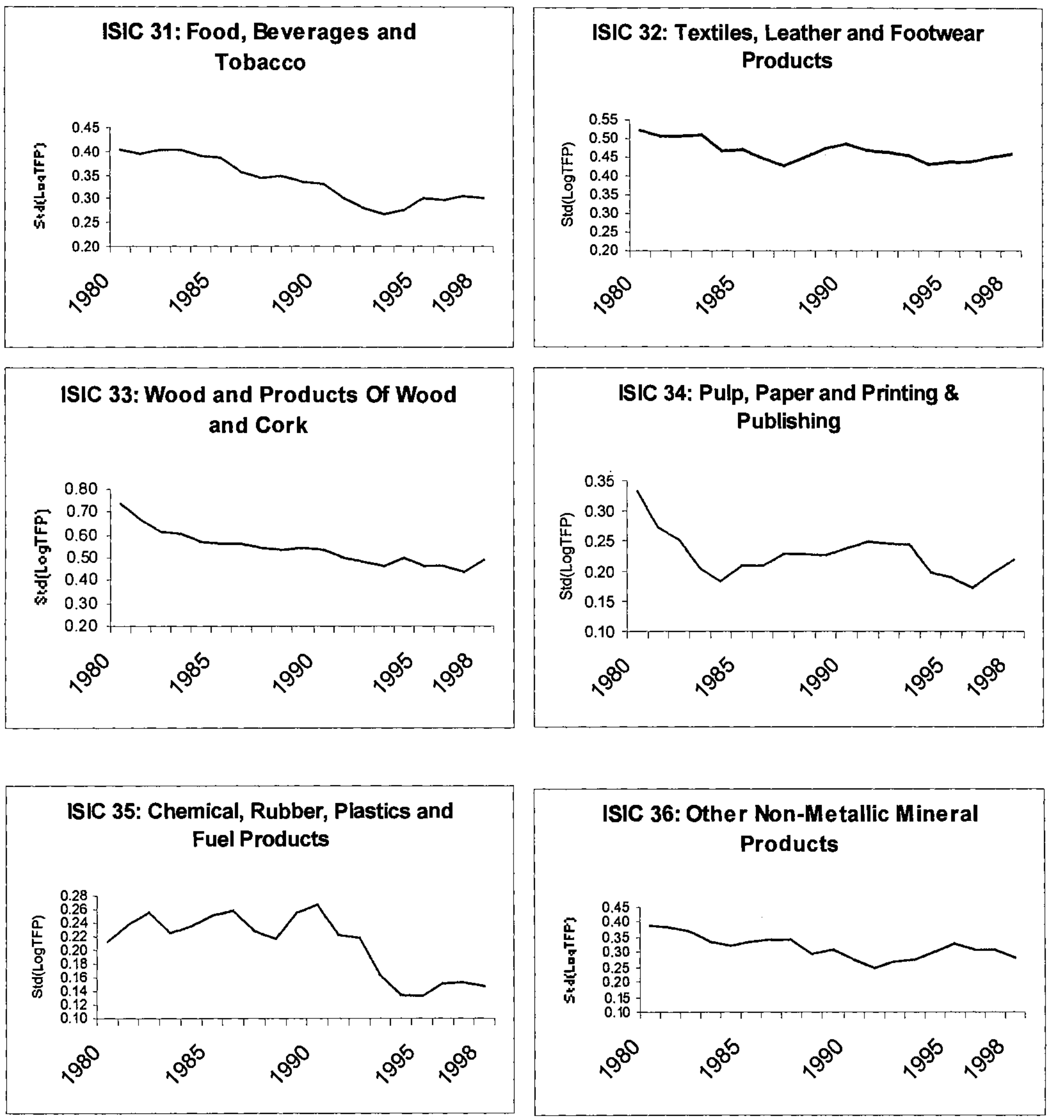
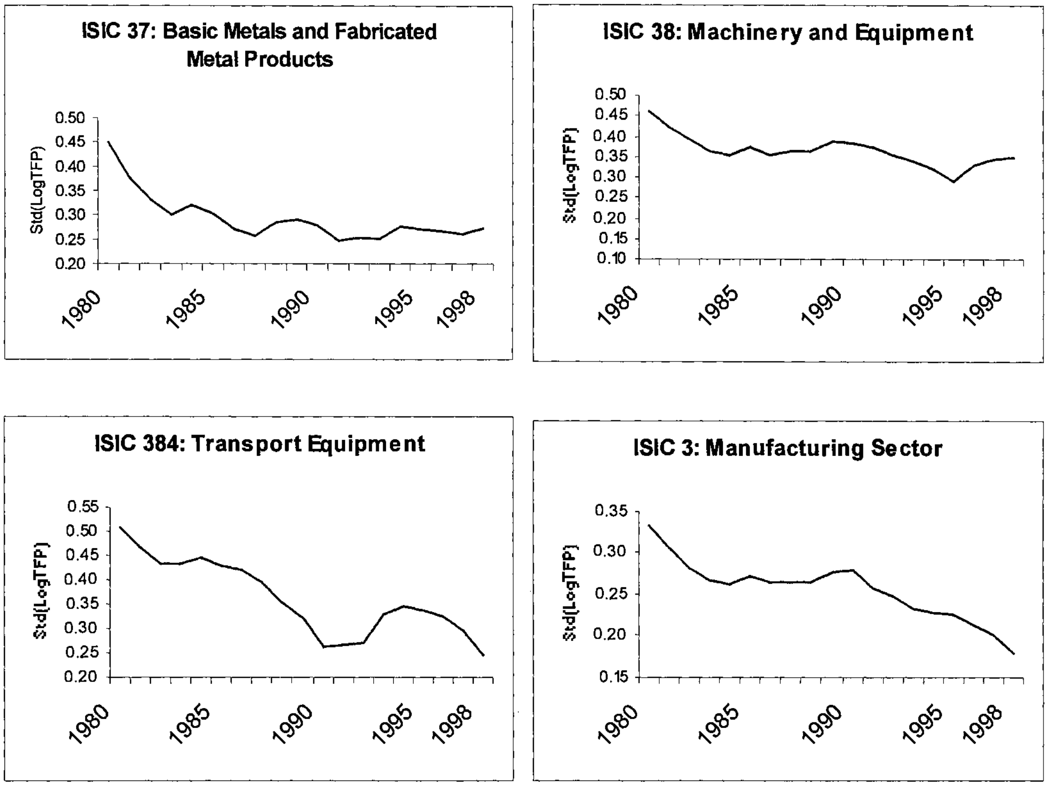


Figure 4.1 (~) Standard Deviation of (Log) TFP by Manufacturing Branch



4.3 Economic Freedom and Total Factor Productivity

Total factor productivity (TFP) measures the "efficiency" with which inputs are used to produce outputs. For instance, it is said that its growth over time is an important contributor to economic growth. It is also known that it varies over space, with large cities having higher levels of TFP. In both the growth context and the spatial context, it is believed that its level and growth is somehow related to the growth and diffusion of new knowledge or ideas. Hayek has emphasized the market system's codification and transmission of information as an important aspect of its economic success. In particular, by using tacit information or what Jensen and Meckling (1992) call specific knowledge, the market system brings previously unused knowledge - new knowledge - into economical use. This discovery dimension of markets, of course, has been emphasized in Austrian economics. In this section, the dissertation first considers economic freedom as a determinant of TFP differentials.

4.3.1 Economic Freedom and Relative Total Factor Productivity Levels

As described in chapter III, the TFP index has been calculated for 12 OECD countries for the manufacturing sector and for 9 manufacturing branches. It should be noted that Transport Equipment is a sub branch of Machinery and Equipment. Table 3.6 in Chapter III shows the productivity levels relative to the United States in 1990 for the manufacturing sector for 12 OECD countries and also relative to the United States on an annual basis. In the first case, the United States index is put at 100 for 1990, and, in the second case, it is put at 100 each year.

A panel data set was created for 4 cross-sections for the years 1980, 1985, 1990, and 1995. To help control measurement error, the dissertation took a three-year average of the productivity levels (centered on the relevant year.) The years were chosen in order to correspond to years for which FreeTheWorld[1] produces its index of economic freedom (EFW). This index, which has a potential range of 1 to 10 (with 10 the highest level of freedom), has been used in numerous studies; it purports to measure the extent to which markets are used to allocate resources. EFW is concerned with both institutions and policy. Among the areas it emphasizes, are a stable currency, the use of markets to allocate capital, and the existence and enforcement of a property rights regime that

[1] For discussion on data, see Data Description and Sources in the Appendix of this dissertation.

supports market allocations. It is also concerned with the extent to which prices and behaviour are distorted by regulations and controls.

This section investigates the effects of economic freedom, membership in the European Union (EU) and time on the relative productivity level, using the following model specifications:

$$\text{Model 1: } TFP_{ijt} = \alpha + \beta_1 \cdot EF_{it} + \varepsilon_i \quad (4.8)$$

$$\text{Model 2: } TFP_{ijt} = \alpha + \beta_1 \cdot EF_{it} + \beta_2 \cdot EU + \varepsilon_i \quad (4.9)$$

$$\text{Model 3: } TFP_{ijt} = \alpha + \beta_1 \cdot EF_{it} + \beta_2 \cdot EU + \beta_3 \cdot Time + \varepsilon_i \quad (4.10)$$

$$\text{Model 4: } TFP_{ijt} = \alpha + \beta_1 \cdot EF_{it} + \beta_2 \cdot EU + \beta_3 \cdot Time + \beta_4 \cdot EU \cdot Time + \varepsilon_i \quad (4.11)$$

$$\text{Model 5: } TFP_{ijt} = \alpha + \beta_1 \cdot EF_{it} + \beta_5 \cdot Country + \varepsilon_i \quad (4.12)$$

Table 4.2 shows the results for regression specifications, named Model 1- Model 5. The results for the manufacturing sector show a positive association between economic freedom and TFP. The simple regression of TFP on economic freedom yields a positive coefficient of 0.11 with a t-statistic of more than 5.0. Adding a dummy variable for membership in the European Union results in the coefficient dropping to 0.10. The coefficient on the EU dummy is not significant. Adding a time variable to the equation similarly has little effect.

It is only in Model 4, where the EU dummy is interacted with the freedom variable, that the basic result is affected. Now the freedom coefficient is 0.18, the EU coefficient is 0.83, and the interaction of the two variables has a coefficient of -0.11. This simple equation results in an adjusted R^2 of 0.48. In effect, the data show two different relationships between TFP and economic freedom.

Table 4.2 Regressions of Relative Productivity Level on Economic Freedom

4.2.1 Manufacturing Sector

	Model 1	Model 2	Model 3	Model 4	Model 5
Economic Freedom (EF)	0.105	0.101	0.119	0.179	0.051
	5.280	*4.964*	*4.773*	*5.857*	*3.497*
European Member (EU)		0.032	0.026	0.828	
		0.941	*0.758*	*3.025*	
Time Dummy			-0.022	-0.025	
			-1.224	*-1.510*	
EF·EU				-0.110	
				-2.950	
Country Dummy					Yes
Crossover				7.5	
$\overline{R}^2$	0.370	0.368	0.375	0.475	0.850

4.2.2 Textiles, Leather and Footwear Products

	Model 1	Model 2	Model 3	Model 4	Model 5
Economic Freedom (EF)	0.107	0.108	0.184	0.296	-0.010
	3.385	*3.281*	*5.234*	*7.551*	*-0.419*
European Member (EU)		-0.003	-0.029	1.473	
		-0.046	*-0.599*	*4.194*	
Time Dummy			-0.095	-0.101	
			-3.733	*-4.724*	
EF·EU				-0.206	
				-4.304	
Country Dummy					Yes
Crossover				7.0	
$\overline{R}^2$	0.176	0.155	0.358	0.553	0.783

Note: The italicized numbers represent t-ratios.

4.2.3 Food, Beverages and Tobacco

	Model 1	Model 2	Model 3	Model 4	Model 5
Economic Freedom (EF)	0.077	0.067	0.095	0.140	0.018
	2.812	*2.442*	*2.892*	*3.226*	*1.064*
European Member (EU)		0.087	0.077	0.675	
		1.919	*1.707*	*1.734*	
Time Dummy			-0.036	-0.038	
			-1.505	*-1.620*	
EF·EU				-0.082	
				-1.546	
Country Dummy					Yes
Crossover				8.4	
$\overline{R}^2$	0.117	0.170	0.194	0.221	0.852

4.2.4 Pulp, Paper and Printing and Publishing

	Model 1	Model 2	Model 3	Model 4	Model 5
Economic Freedom (EF)	0.148	0.121	0.114	0.175	0.098
	4.805	*4.926*	*3.715*	*4.522*	*3.551*
European Member (EU)		0.216	0.219	1.041	
		5.265	*5.219*	*3.002*	
Time Dummy			0.009	0.007	
			0.428	*0.310*	
EF· EU				-0.113	
				-2.387	
Country Dummy					Yes
Crossover				9.4	
$\overline{R}^2$	0.323	0.586	0.577	0.622	0.752

Note: The italicized numbers represent t-ratios.

4.2.5 Chemical, Rubber, Plastics and Fuel Products

	Model 1	Model 2	Model 3	Model 4	Model 5
Economic Freedom (EF)	-0.051	-0.076	-0.066	-0.044	-0.085
	-1.375	-2.282	-1.592	-0.785	-2.287
European Member (EU)		0.202	0.199	0.496	
		3.644	*3.507*	*0.990*	
Time Dummy			-0.013	-0.014	
			-0.419	*-0.451*	
EF·EU				-0.041	
				-0.597	
Country Dummy					Yes
Crossover				-	
$\overline{R}^2$	-0.004	0.223	0.207	0.193	0.547

4.2.6 Other Non-Metallic Mineral Products

	Model 1	Model 2	Model 3	Model 4	Model 5
Economic Freedom (EF)	0.125	0.135	0.148	0.246	0.089
	4.114	*4.386*	*3.889*	*5.361*	*4.503*
European Member (EU)		-0.075	-0.080	1.231	
		-1.473	*-1.534*	*2.996*	
Time Dummy			-0.017	-0.021	
			-0.604	*-0.860*	
EF·EU				-0.180	
				-3.212	
Country Dummy					Yes
Crossover				6.8	
$\overline{R}^2$	0.253	0.272	0.260	0.400	0.859

Note: The italicized numbers represent t-ratios.

4.2.7 Basic Metals and Fabricated Metal Products

	Model 1	Model 2	Model 3	Model 4	Model 5
Economic Freedom (EF)	0.131	0.139	0.121	0.177	0.123
	4.961	*5.228*	*3.695*	*4.182*	*5.647*
European Member (EU)		-0.066	-0.059	0.689	
		-1.479	*-1.323*	*1.817*	
Time Dummy			0.022	0.020	
			0.942	*0.857*	
EF·EU				-0.102	
				-1.987	
Country Dummy					Yes
Crossover				6.9	
$\overline{R}^2$	0.339	0.357	0.354	0.398	0.795

4.2.8 Machinery and Equipment

	Model 1	Model 2	Model 3	Model 4	Model 5
Economic Freedom (EF)	0.105	0.110	0.128	0.216	0.050
	3.304	*3.367*	*3.156*	*4.267*	*1.808*
European Member (EU)		-0.040	-0.046	1.133	
		-0.733	*-0.831*	*2.502*	
Time Dummy			-0.022	-0.026	
			-0.745	*-0.952*	
EF·EU				-0.161	
				-2.621	
Country Dummy					Yes
Crossover				7.0	
$\overline{R}^2$	0.168	0.158	0.148	0.257	0.711

Note: The italicized numbers represent t-ratios.

4.2.9 Transport Equipment

	Model 1	Model 2	Model 3	Model 4	Model 5
Economic Freedom (EF)	0.098	0.111	0.134	0.171	0.066
	2.823	*3.204*	*3.136*	*2.998*	*2.761*
European Member (EU)		-0.103	-0.111	0.388	
		-1.791	*-1.903*	*0.761*	
Time Dummy			-0.028	-0.030	
			-0.921	*-0.978*	
EF·EU				-0.068	
				-0.985	
Country Dummy					Yes
Crossover				5.5	
$\overline{R}^2$	0.118	0.162	0.158	0.157	0.810

Note: The italicized numbers represent t-ratios.

Figure 4.2: Relative TFP and Economic Freedom

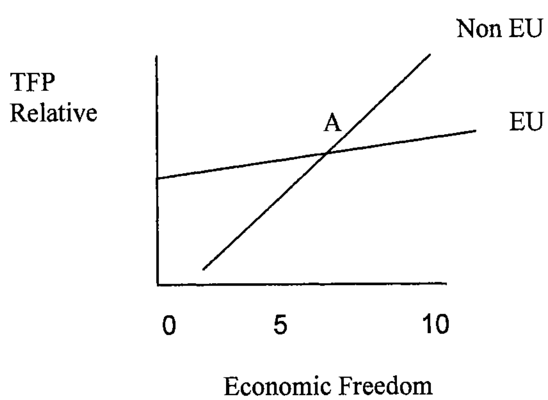


Figure 4.2 illustrates the two relationships. For the EU countries, TFP increases less rapidly with economic freedom than it does for the other countries[1]. The results for the effect of economic freedom, are similar when Korea is excluded. In most industries, the EU relationship starts above the relationship for the other countries, but the more rapidly increasing TFP with economic freedom for the other countries results in their TFP crossing over that of the EU countries at an economic freedom index value of about 7.

The estimates for all of the industries in ***Table 4.2*** show this pattern of a smaller effect of a change in economic freedom on the productivity level of EU countries. The coefficient on the interactive term is statistically significant for 5 of the 8 manufacturing branches. For 4 of the 5 significant coefficients the crossover point, A, occurs at a level of economic freedom of about 7. The crossover point is significant because it is before this point that membership in the EU is associated with a country having a higher productivity relative than would be predicted on the basis of its level of economic freedom. In other words, less free countries in the EU are more productive than less free OECD countries outside the EU. Beyond the crossover point, the opposite holds. Countries outside the EU with a certain level of economic freedom have a greater productivity relative than countries in the EU with the same level of economic freedom.

An examination of the freedom ratings in ***Table 4.3*** suggest being in the EU favors France relative to Austria in the sense that they as relatively less economically free countries, France has a higher predicted TFP than Austria. Similarly, the ratings suggest that being outside the EU favors Canada relative to the Netherlands in the opposite sense—as relatively more economically free countries, Canada has a greater predicted

[1] This relationship is not robust with respect to the countries included. If Korea is excluded from the data set, there is no big difference in slopes between EU countries and Non-EU countires.

boost to its productivity from its economic freedom than does the Netherlands with about the same level of economic freedom.

Table 4.3. Average Economic Freedom Ratings by Country

Non EU		EU	
Austria	7.1	Belgium	8.0
Canada	8.1	France	7.0
Finland	7.4	Great Britain	7.9
Korea	6.2	Italy	6.5
Norway	7.1	Netherlands	8.1
Sweden	7.0		

Data: FreetheWorld.com

Does being in the EU mean that the productivity disadvantages of less economic freedom are alleviated for countries that are relatively less free and that the productivity advantages of more economic freedom similarly are reduced for countries with greater freedom? It would be premature to make that claim on the basis of these results. Nevertheless, it is proposition that deserves more exploration, both to determine whether it is true and, if so, why it occurs.

The final regression in ***Table 4.2*** for the manufacturing sector and each branch is a fixed effects regression with dummy variables for each country. The only variable other than the country dummies is economic freedom. This coefficient is positive and significant for the manufacturing sector and for 5 of the 8 branches, although the freedom coefficient for the *Machinery and Equipment* industry has an associated t statistic of only 1.81. Moreover, the freedom coefficient for the *Chemicals* industry is negative and significant. By estimating with country fixed effects, it is possible to control for time invariant variables that may have been omitted from the regressions previously discussed. In these estimates the freedom coefficient is smaller than it was in the corresponding previous regressions.

This analysis of productivity levels supports the proposition that economic freedom is associated with greater productivity, presumably because it is associated with greater economic efficiency. This does not tell, however, whether economic freedom has a positive effect on productivity growth. This proposition is examined in the remainder of this section.

4.3.2 Economic Freedom and Total Factor Productivity Growth

This section uses the convergence model of Section 4.2.1 to test for an association between economic freedom and TFP growth. Productivity levels relative to the United States are calculated by taking the 3-year average of the levels centered on the years 1980, 1985, 1990, and 1995. For the period 1980 to 85, 1985 to 90, and 90 to 1995, the averages relative to the United States centered on 1980, 1985, 1990, and 1995, are used to calculate the growth rate in TFP. The growth rates for these three periods are the annualised log difference in these productivity levels. The growth rate for the period of 1995-1998 is the log difference between the 1998 and 1995 productivity levels, again annualised. The data is split into 4 cross-sections so as to test for convergence and also test for the effects of economic freedom.

The empirical models are specified for investigating the links between economic freedom and TFP growth. The models are designed to regress the TFP growth rate

($\Delta \ln(A_{it})$) on the productivity gap from the frontier ($\ln \hat{A}_{i,t} = \ln A_{i,t} - \ln A_{F,t}$), economic freedom (EF) and country dummy variables, as following:

Model 1: $\Delta \ln(A_{it}) = \beta_1 \cdot \hat{A}_{it} + \beta_2 \cdot EF_{it} + \varepsilon_i$ (4.13)

Model 2: $\Delta \ln(A_{it}) = \beta_1 \cdot \hat{A}_{it} + \beta_2 \cdot EF_{it} + \sum_1^{11} \lambda_i \cdot CountryDummy_i + \varepsilon_i$ (4.14)

Table 4.4 gives the results of two model specifications for each industry. The results were obtained on the basis of 10 counties, which excluded the frontier country (U.S.A) and Korea. In the manufacturing sector as a whole and most manufacturing industries, the addition of the country fixed effects results in a large increase in the adjusted R^2, suggesting that the fixed effects specification is the appropriate one. The coefficients for the productivity gap are negative in all industries (except ISIC 32 and ISIC 33). Note that the t-statistics become larger in all industries (except ISIC 3 and ISIC 384), when taking consideration of country fixed effect. The coefficient for economic freedom is positive in most models (except ISIC31, ISIC 32 and ISIC 35) and significant. These empirical results indicate that that –convergence is occurring, expressed by the negative coefficient of relative productivity level. The results also confirm that TFP growth is positively related to economic freedom in the manufacturing sector and most manufacturing branches. In other word, TFP growth of manufacturing industries increases when the degree of economic freedom grows up.

4.3.3 Conclusion

The results of this investigation of productivity convergence and the effect of economic freedom on productivity are encouraging. Over the period 1980-1998, there is

Table 4.4: The effects of Relative Productivity Level and Economic Freedom on Annual Growth Rate of TFP (10 Countries)

	Dependent Variable: The Annual Rate of Productivity Growth Over a 5 Year Period					
	Model: Without Country Dummy			Model: With Country Dummy		
	RTFP	EF	R^2	RTFP	EF	R^2
ISIC 3	-0.0917 (-4.00)	0.0093 (2.59)	0.31	-0.1416 (-3.85)	0.0121 (2.57)	0.54
ISIC 31	-0.0264 (-2.54)	-0.0006 (-0.15)	0.19	-0.0927 (-3.81)	-0.0050 (-1.01)	0.59
ISIC 32	-0.0785 (-3.22)	0.0046 (0.76)	0.22	-0.1570 (-5.77)	-0.0008 (-0.16)	0.67
ISIC 33	0.0144 (0.71)	0.0078 (1.24)	0.08	0.0408 (1.57)	0.0204 (2.26)	0.33
ISIC 34	-0.0643 (-2.29)	0.0023 (0.40)	0.14	-0.1422 (-3.91)	0.0079 (1.13)	0.53
ISIC 35	0.0036 (0.08)	-0.0046 (-0.52)	0.01	0.0624 (1.03)	-0.0145 (-1.24)	0.14
ISIC 36	-0.0557 (-2.67)	0.0122 (2.44)	0.20	-0.1942 (-5.11)	0.0338 (4.62)	0.56
ISIC 37	-0.0617 (-2.28)	0.0082 (1.05)	0.12	-0.1852 (-3.73)	0.0380 (2.97)	0.42
ISIC 38	-0.0897 (-3.68)	0.0159 (2.30)	0.29	-0.1930 (-4.06)	0.0402 (4.03)	0.57
ISIC 384	-0.0598 (-3.45)	0.0155 (2.12)	0.26	-0.0797 (-1.93)	0.0278 (2.30)	0.34

Note: 1) RTFP means a relative productivity level, defined as following;

$$RTFP \equiv \ln \hat{A}_{i,t} = \ln A_{i,t} - \ln A_{F,t}$$

2) The coefficient were estimated from 10-country sample (U.S.A and Korea, excluded).

3) The numbers in the parenthesis are t-statistics of the coefficients.

strong evidence for β-convergence. In addition, there is strong evidence for a positive effect of economic freedom on productivity levels. There is also the intriguing result that the relationship between economic freedom and productivity is systematically different for EU and non- EU countries in the OECD. The empirical results also provide that there is a positive effect of economic freedom on productivity growth in the manufacturing sector and even in the manufacturing branches except several industries such as ISIC 31, ISIC 32 and ISIC 35.

4.4 TFP growth and R&D Activity

4.4.1 The role of R&D activity in TFP growth

As described at previous section, technology change is usually measured by changes in the TFP index at the industry-level or economy-wide level. There are some main factors[1] governing the changes that may be wholly or partially "endogenous" to the economic system. One factor determining technical change is new knowledge, which is spreading through training and adoptions of new equipment, embodied with the current "state-of-art". Another factor is said new techniques, which can be considered as outward shifts in the "production possibility frontier". This factor is obtained by conscious efforts by scientists, entrepreneurs and researchers, both formal and informal, to improve the existing state of technology. Much of existing theoretical literature puts an emphasis on the contribution of R&D expenditure to economic growth. This suggests that TFP can be expressed as a function of past R&D investment. Griliches (1998) states that all productivity growth is related to all expenditure on R&D and implies that study on

[1] Zvi Grikich (1998) explains these factors as major circumstances in addition to institutions generating the new scientific knowledge.

economic growth should estimate statistically the part of productivity growth that can be attributed to R&D.

As Griffith et al (2000) describes in detail, there are two roles or 'faces' of research and development (R&D) activity. The first one is to stimulate innovation; the other is to facilitate the adoption and imitation of the discoveries of the frontier economy. The former has received the most attention in the literature. Because some knowledge is 'tacit', technology transfer is not immediate and is costly. Some R&D activity is crucial for technology transfer.

The dissertation showed in Chapter III that there were consistent differences in TFP levels of manufacturing industries across 12 OECD countries. Its convergence analysis indicated in previous section of this chapter, not only these gaps in TFP level became smaller over time (β-convergence) but also the TFP discrepancies across countries at the same time horizon (σ-convergence) became narrower, implied by the scale of standard deviation of TFP. The convergence results imply the opportunity for less advanced countries to benefit from technology transfer.

So, as a further step, this dissertation investigates whether technology transfer or R&D activity takes an important role of determining TFP growth on an overall manufacturing industry level for a country behind the technological frontier. The dissertation provides empirical evidences on the effects of R&D activity and relative TFP on the TFP growth on the basis of the pooled industry data set. R&D activity is measured by R&D expenditure, which comes from OECD Research and Development Expenditure in Industry (Analytical Business Enterprise Research and Development database:

ANBERD). The ANBERD was designed to provide analysts with a comprehensive and internationally comparable data set on industrial R&D expenditure.

There is a large literature[1] on R&D activity and TFP growth, undertaken at the whole-economy level. Only recently, however, have studies investigated the link between R&D activity and TFP growth across countries. One of most recent studies is Griffith et al (2000), which investigates innovation and imitation channels by integrating manufacturing industries under the assumption that all industries are equally capable of gaining spillover from all other including the frontier country.

The dissertation investigates technology transfer using a country's TFP difference from the frontier country for all manufacturing industries in the sample. Theoretically, the frontier in technology is defined as the country with the highest level of total factor productivity (TFP). TFP difference is thought of as a direct measure of the potential for technology transfer. The dissertation examines whether R&D activity has a direct effect on the TFP growth of non-frontier country, through what Griffith et al. term an "innovation channel". In addition, the dissertation investigates whether TFP growth depends upon a country's level of TFP relative to the frontier as an "imitation or adoption channel", again following Griffith et al. TFPs and relative TFPs are measured using the Malmquist TFP index, which are obtained in Chapter 3 of this dissertation. The convergence theory predicts that the farther a country lies behind the technological frontier, the greater the potential for R&D activity to increase TFP growth through technology transfer.

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[1] See, for example, Gerschenkron (1962), Abramovitz (1986), Benhabib and Spiegel (1994) and Parente and Prescott (1994).

4.4.2 Econometric Model for R&D Activity and TFP Growth

In this section, the dissertation follows Griffith et al (2000) in order to specify an econometric model. Denote countries by $i = 1,...,N$ and industries of manufacturing sector by $j = 1,...,J$. Value added (Y) of the manufacturing sector at time t is produced with labor (L) and physical capital stocks (K) according a standard neoclassical production function technology as following:

$$Y_{ijt} = A_{ijt} \cdot F_j(L_{ijt}, K_{ijt}) \tag{4.15}$$

where A_{ijt} is an index of technical efficiency or Total Factor Productivity (TFP). $F_j(.,.)$ is assumed to have constant returns to scale (CRS technology) and to exhibit diminishing marginal returns to any increase in one factor input alone. TFP (A_{ijt}) is assumed to vary across countries i, industries j and over time t. The frontier ($i = F$) is expressed as an economy with the highest level of TFP in industry j at time t.

Following Griffith et al (2000), TFP is assumed as a function of the stock of knowledge (G_{ijt}) and a residual set of influences (B_{ijt}), which determines the speed of technology diffusion. This link is expressed as:

$$A_{ijt} = \psi(B_{ijt}, G_{ijt}) \tag{4.16}$$

The dynamics of TFP with the G_{ijt} and B_{ijt} is obtained by taking logarithms in (4.18) and differentiating with respect to time as following:

$$\frac{\dot{A}_{ijt}}{A_{ijt}} = v_{ijt} \cdot \frac{\dot{B}_{ijt}}{B_{ijt}} + \eta_{ijt} \cdot \frac{\dot{G}_{ijt}}{G_{ijt}} \tag{4.17}$$

where $\eta \equiv (dY / dG) \cdot (G / Y)$ is the elasticity of output with respect to R&D knowledge stocks (G) and $v \equiv (dY / dB) \cdot (B / Y)$ is the elasticity of output with respect to the residual set of influences (B). By terming real R&D expenditure by R and the depreciation rate of R&D knowledge stocks by φ, the dynamic of real R&D knowledge stocks is defined as $\dot{G} = R - \varphi \cdot G$. Furthermore, if φ is assumed to be very small ($\varphi \cong 0$), then $\dot{G} = R$. Under this assumption, equation (4.17) can be redefined as:

$$\frac{\dot{A}_{ijt}}{A_{ijt}} = v_{ijt} \cdot \frac{\dot{B}_{ijt}}{B_{ijt}} + \rho_{ijt} \cdot \frac{R_{ijt}}{Y_{ijt}} \tag{4.18}$$

where $\rho = dY / dG$ is the rate of return or marginal product of R&D knowledge stocks. The dynamic movement of TFP (4.18) can be redefined in discrete time under the assumption that TFP is determined by the R&D activity in one period early:

$$\Delta \ln A_{ijt} = v_{ijt} \cdot \Delta \ln B_{ijt} + \rho_{ijt} \cdot \frac{R_{ijt-1}}{Y_{ijt-1}} \tag{4.19}$$

In equation (4.19), the growth rate of TFP, expressed as $\Delta \ln A_{ijt}$, is modeled as a reaction of the residual influences and the R&D activity.

The theoretical rationale for this relationship is based on endogenous growth theory, which put emphases on the non-rivalry and partial excludability of knowledge. Thanks to these properties of knowledge, innovators can appropriate more returns from the new discovery. Thus, the economic incentive to engage in R&D activity is the expected flow of profits from the patents, which are given to a newly developed technology. As a result, the R&D activity for innovation determines the TFP growth rate of the economy as a whole. (For discussion in depth, see Griffith et al, 2000; Jones, 1997; Aghion and Howitt, 1992; Romer, 1990).

Equation (4.19) implies that R&D activity has a direct effect on TFP growth. As an extension, Griffith et al (2000) provide a model in which the possibility of technology transfer from the frontier country to followers within the same industries is allowed. This model implies that TFP growth in the frontier country induces faster TFP growth of the following countries by shifting out the production possibility set. And the speed of diffusion of technology is determined by the relative TFP of any country and the industry specific characteristics. Therefore, the residual set of influences is modeled as:

$$\Delta \ln B_{ijt} = \pi_{ijt} \cdot \Delta \ln A_{Fjt} - \sigma_{ijt} \cdot \ln(\frac{A_i}{A_F})_{jt-1} + \mu_{ijt} \qquad (4.20)$$

where $\ln(A_i / A_F)_{jt}$ indicates the relative level of TFP and μ_{ijt} captures all other stochastic influences on TFP. It should be noted that $\ln(A_i / A_F)_{jt}$ is negative, since TFP of a follower lies below that of the frontier. Thus, the farther a country i lies behind the technological frontier, the greater potential for technology transfer, which is expressed as a large $\Delta \ln B_{ijt}$. This reasoning implies that technology transfer has a negative estimated coefficient on $\ln(A_i / A_F)_{jt}$ in equation (4.20). Substituting this relationship into the equation (4.19), the growth rate of TFP can be expressed as:

$$\Delta \ln A_{ijt} = \beta_{ijt} \cdot \Delta \ln A_{Fjt} - \delta_{ijt} \cdot \ln(\frac{A_i}{A_F})_{jt-1} + \rho_{ijt} \cdot (\frac{R}{Y})_{ijt-1} + \mu_{ijt} \qquad (4.21)$$

where β_{ijt} is the instantaneous effect of TFP change of the frontier ($\Delta \ln A_{Fjt}$) on the growth rate of non-frontier countries, δ_{ijt} captures the rate of technology transfer and ρ_{ijt} represents the marginal product of R&D intensity (R / Y).

Griffith et al (2000) suggests that most theoretical studies on R&D activity and growth focuses on the links between R&D activity and innovation, which is expressed as one main part of "two faces of R&D" [1]. Another face of R&D activity is based on the theoretical literature that R&D activity may play an important role in enabling economic entities to imitate or adopt existing technology. In short, technology imitation or adoption is the other face of R&D activity, implying that an actively researching country can more easily learn about the current-state-of-art technologies and has a greater ability to imitate those technologies.

The rate of technology transfer (δ_{ijt}) is assumed to be a function of R&D activity as following:

$$\delta_{ijt} = \delta_1 + \delta_2 (\frac{R}{Y})_{ijt-1} \qquad (4.22)$$

By substituting (4.22) into (4.21), the equation of TFP growth is redefined by Griffith et al. as:

$$\Delta \ln A_{ijt} = \beta \cdot \Delta \ln A_{Fjt} - \delta_1 \cdot \ln(\frac{A_i}{A_F})_{jt-1} - \delta_2 \cdot (\frac{R}{Y})_{ijt-1} \cdot \ln(\frac{A_i}{A_F})_{jt-1} + \rho \cdot (\frac{R}{Y})_{ijt-1} + \mu_{ijt} \qquad (4.23)$$

Equation (4.23) represents that the growth rate of TFP ($\Delta \ln A_{ijt}$) is determined by R&D activity as both a linear and an interaction term with the TFP gap ($\ln(A_i / A_F)_{jt-1}$). The model imposes common coefficients on TFP growth of the frontier (β) and the linear R&D intensity coefficient (ρ). Under equation (4.23), the return to additional R&D activity depends on how far an industry *j* of a non-frontier country is behind the industry of frontier country. Theoretical reasoning on the marginal return of R&D activity predicts that the social return to R&D investment for non-frontier countries is

[1] Cohen and Levinthal (1989), Grossman and Helpman (1991) and provide other types of theoretical models, which show links between R&D and both an innovative and imitative role.

greater than that of the frontier country, since non-frontier countries have lower relative levels of TFP. The predicted results can be another version of explanation on the convergence theory, especially, in term of β-convergence, implying the tendency of countries with relatively high initial levels of TFP to grow relatively slowly.

4.4.3 **Empirical Results**

For empirical model (4-23), all manufacturing industries were pooled into one data set. From all the countries, the frontier position in a specific industry was determined. Under this data structure, $\Delta \ln A_{ijt}$ indicates the annual growth rate of TFP for eight 2-digit industries and one 3-digit industry (ISIC 384) of 12 countries during 1980-1998. It should be noted that the observations of $\Delta \ln A_{Fjt}$ represent the frontier positions in a specific industry j at time t, and are changing with respect to industry and time. This implies that the industry frontier position of a country is changing over time.

Table 4.5 provides empirical evidence of significant associations between TFP growth and TFP level of the frontier, relative TFP, interaction of R&D activity and relative TFP, and a country's R&D activity in a specific industry.

The upper portion of Table 4.5 provides the empirical results without controlling time effects, while the bottom portion shows the results with consideration of time effects. In Model 1, 2, 3 and 4, the estimate represents the independent effect of each factor on the TFP growth rate of the follower countries, respectively. Each factor shows the predicted result and is statistically significant.

In Model 1, the coefficient for $\Delta \ln A_{Fjt}$ looks clear regardless of time effects. The positive coefficient with a great significance (t-statistics: 13.47 and 13.08, respectively) dictates that the frontier country leads the TFP growth rate of the follower. In Model 2, the coefficient for relative TFP term ($\ln(A_i / A_F)$) is negative and highly significant (t-statistics: -8.24 and 9.0, respectively), indicating that within each industry the countries that are further behind the frontier experience higher rates of productivity growth. For this interpretation, note that $\ln(A_i / A_F)$ is negative. The coefficient of $(R / Y) \cdot \ln(A_i / A_F)$ in Model 4 indicates the interaction effect between R&D activity and relative TFP. The theory predicted sign is negative due to the effect of $\ln(A_i / A_F)$. This interaction effect represents the imitation or adoption of the existing technology. The effect indicates that the greater R&D activity and larger discrepancy from the frontier in TFP induces the big imitation or adoption effect of technology transfer. In Model 4, the coefficient for (R / Y) indicates the innovation effect of R&D activity. Theoretically, it is clear that an active R&D activity results in fast TFP growth at the frontier position or the follower countries.

In Model 5, the TFP growth in the frontier ($\Delta \ln A_{Fjt}$) and the relative TFP ($\ln(A_i / A_F)$) account for the growth rate of TFP ($\Delta \ln A_{ijt}$). This model shows that there exist very significant associations. It should be noted that there are no big differences in the scale of coefficients compared to those in Model 1 and Model 2. Furthermore, the coefficients are highly significant (t-statistics: 12.62 for $\Delta \ln A_{Fjt}$ and –9.64 for $\ln(A_i / A_F)$. Even when controlling the time effect, there is no big difference in the influence of each factor. This evidence implies that time factor is not important in explaining the annual TFP growth.

In Model 7, TFP growth is simultaneously accounted for by all the factors of equation (4.23). The effects of $\Delta \ln A_{Fjt}$ and $\ln(A_i / A_F)$ are theoretically valid and statistically

Table 4.5: Regression Results of Technology Transfer Effects of R&D Expenditure at all Manufacturing Industries.

Variable	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
Intercept	0.0114	0.0037	0.0010	-0.0044	0.0047	-0.0071	-0.0092
	(1.30)	(0.28)	(0.09)	(-0.58)	(0.37)	(-0.70)	(-0.87)
$\Delta \ln A_{Fjt}$	0.5751				0.5631	0.4874	0.4874
	(13.47)				(12.62)	(12.06)	(12.06)
$\ln(A_i / A_F)_{jt-1}$		-0.1054			-0.1177	-0.0727	-0.0764
		(-8.24)			(-9.64)	(-6.86)	(-6.43)
$(R/Y) \cdot \ln(A_i / A_F)_{jt-1}$			-0.3239			-0.1204	-0.0316
			(-4.34)			(-1.60)	(-0.21)
$(R/Y)_{ijt-1}$				0.1004			0.0529
				(2.79)			(0.70)
Country Dummy	yes	yes	yes	yes	yes	yes	yes
$\overline{R}^2$	0.10	0.04	0.01	0.01	0.13	0.13	0.13
Observation No:	1,680	1,513	1,348	1,508	1,513	1,348	1,348
Intercept	0.0187	0.0269	0.0069	0.0002	0.0232	-0.0002	-0.0023
	(1.81)	(1.86)	(0.58)	(0.02)	(1.68)	(-0.02)	(-0.19)
$\Delta \ln A_{Fjt}$	0.5615				0.5480	0.4884	0.4886
	(13.08)				(12.28)	(12.00)	(12.00)
$\ln(A_i / A_F)_{jt-1}$		-0.1157			-0.1259	-0.0763	-0.0796
		(-9.00)			(-10.24)	(-7.03)	(-6.59)
$(R/Y) \cdot \ln(A_i / A_F)_{jt-1}$			-0.3276			-0.1084	-0.0303
			(-4.36)			(-1.42)	(-0.20)
$(R/Y)_{ijt-1}$				0.0977			0.0466
				(2.69)			(0.61)
Country Dummy	yes	yes	yes	yes	yes	yes	yes
Time Dummy	yes	yes	yes	yes	yes	yes	yes
$\overline{R}^2$	0.10	0.06	0.01	0.00	0.14	0.13	0.13

Note: 1) Regression results of the upper table are estimated without taking the time effects (No Time Dummy Model).

2) The numbers in the parenthesis indicate t-statistics.

significant. However, the effects of $(R/Y)\cdot\ln(A_i/A_F)$ and (R/Y) are not significant at a conventional significant level. Controlling the time effect the bottom part of Table 4.5 shows does not affect the significance of the coefficients for $(R/Y)\cdot\ \ln(A_i/A_F)$ and (R/Y).

In conclusion, the empirical results show that there are theoretically predicted and significant effects of technology transfer, which are represented by $\Delta\ln A_{Fjt}$ and $\ln(A_i/A_F)$. These results could be explanations for $\beta-$convergence in the previous section of this chapter. In Model 7, particularly, $\Delta\ln A_{ijt}$ attributed to two different effects; one is the convergence motion ($\Delta\ln A_{Fjt}$ and $\ln(A_i/A_F)$) and the second is the R&D activity ($(R/Y)\cdot\ln(A_i/A_F)$ and (R/Y)). As Model 6 and Model 7 show, the effects of R&D activity on TFP growth are statistically inconclusive. This could be because the effects of $\Delta\ln A_{Fjt}$ and $\ln(A_i/A_F)$ dominate the effects of $(R/Y)\cdot\ln(A_i/A_F)$ and (R/Y) in explaining the TFP growth ($\Delta\ln A_{ijt}$). Another finding is the imitation or adoption effects and the innovation effects of R&D activity on TFP growth in Model 3 and Model 4. These effects provide the reasons why a country needs to concern about the R&D activity in even manufacturing industries. However, it should be noted that these effects become insignificant when simultaneously considering the convergence movement.

Chapter V.

INSTITUTIONS AND ECONOMIC PERFORMANCE

5.1 Overview

Neoclassical growth theory considers investment as the most important source for economic growth. Starting from a long-run equilibrium, an increase in the saving rate is assumed to be accompanied by a corresponding increase in investment. The increased investment results in increases in the capital-labor ratio and hence in output per worker. As the process continues, the economy moves to a new long-run equilibrium with a higher output per worker; output growth per worker, however, ceases because diminishing returns to capital results in smaller and smaller increases in output with the increased capital stock. So the increased saving and investment results in growth in the short run and a higher level of output per worker in the long run. The only source of continuing growth is technical change, which is determined outside the model. In other words, it is taken as exogenous in the neoclassical model. This feature of the model has been criticized because empirical evidence suggests that technical change is a more important source of economic growth than increases in investment.

Similarly, neoclassical growth theory assumes that the rate of saving is determined outside the model and that saving is automatically converted into investment with no consideration of incentives for savers or investors. The new institutional economics criticizes neoclassical theory for ignoring the effect that institutions have on incentives (Jones, 1997). The neoclassical model excludes the effects that institutions with their effect on incentives have on saving, investing, research and development, and the adoption of new technologies. Thus, the new institutional economics can be interpreted as incorporating some elements of endogenous growth theory in its broader critique of neoclassical growth theory.

The literature provides numerous examples of the effects of institutional factors on national economic performance. Those institutional factors have been represented by economic freedom (Dawson, 1998), political freedom (Rodrik, 1997; Dawson, 1998), market openness (Edwards, 1998), and macroeconomic stabilization and institutions for social insurance (Rodrik, 2000). These studies examined the relationship between institutional factors and national economic performance, by investigating how institutional factors influence output growth, TFP growth, or unemployment.

In particular, Adkins, Moomaw and Savvides (2002) use the stochastic frontier approach to investigate the influence of institutions on economic performance, as measured by technical inefficiency. Their study postulates that different countries operate at different distances from a world production frontier. They further suggest that technical inefficiency can be measured by deviations from the production possibility frontier and that these deviations are a function of certain measurable economic and institutional variables. Adkins et al (2002) provide that economic and political institutions contribute to technical inefficiency. Recently, increased attention has been paid to comparing economic performance of a specific sector or industry across regions or countries. In particular, productivity differences of the manufacturing sector across countries have been studied (Harrigan, 1997; Van Ark, 1996; Wagner and Van Ark, 1996). Manufacturing is the sector most studied, partly because it generates much new technology and has important spillover effects to other sectors of the economy. It is also an attractive sector to study in cross-country productivity comparisons because are more likely to be available and more likely to be consistent in measurement across countries.

This section of the dissertation investigates the effects of institutional factors on the technical inefficiencies of manufacturing branches for twelve OECD countries by using the stochastic frontier approach. The dissertation confirms that the country's institutions might cause TFP differences of manufacturing industries in terms of inefficiency across countries. In particular, the dissertation provides statistical evidence on whether the statement of Adkins, Moomaw and Savvides (2002) below holds for the manufacturing sector and for specific industries within that sector:

"Institutions affect economic performance: Increases in economic freedom are associated with improved economic performance in that increases in it move countries closer to the production frontier."

5.2 Stochastic Frontier Model

The stochastic frontier model was independently proposed by Aigner, Lovell and Schmidt (1977), and Meesen and van den Broeck (1977). A number of studies have used this model to determine main factors affecting technical inefficiency for firms, industries, and the entire economy. This model allows for both technical inefficiencies and for random shocks that affect measured output. The most prominent advantage of stochastic frontier models is that the variation in technical efficiency, which is caused by variation of environmental factors in the economy, can be separated from the impact of random shocks on output (Kumbhakar and Lovell, 2000).

A representative frontier production model following Kumbhakar and Lovell (2000)can be written as:

$$Y_i = f(x_i;\beta)\cdot TE_i \tag{5.1}$$

where, Y_i is the output of a specific industry in country $i = 1,2,...I$; x_i, a vector of n inputs used by country i; $f(x_i;\beta)$, the production frontier; and β, a vector of technology parameters to be estimated. TE_i is the technical efficiency of an industry in a specific country. It is the ratio of observed output to maximum feasible output:

$$TE_i = \frac{Y_i}{f(x_i;\beta)} \tag{5.2}$$

Y_i achieves its maximum feasible value if, and only if, $TE_i = 1$. Otherwise $TE_i < 1$ measures the shortfall of observed actual output from maximum feasible output.

Incorporating country-specific random shocks into a production function specifies the stochastic production frontier model. To do so, rewrite equation (5.1) as:

$$Y_i = f(x_i;\beta)\cdot \exp\{v_i\}\cdot TE_i \tag{5.3}$$

where $f(x_i;\beta)\cdot \exp\{v_i\}$ is the stochastic production frontier. The stochastic production frontier consists of two parts: a deterministic part $f(x_i;\beta)$, which is common to all countries, and a country-specific part $\exp\{v_i\}$, which captures the effects of random shocks in each country. With the stochastic production frontier, equation (5.2) becomes

$$TE_i = \frac{Y_i}{f(x_i;\beta)\cdot \exp\{v_i\}}. \tag{5.4}$$

Equation (5.4) defines technical efficiency as the ratio of an observed output to the maximum feasible output in an environment characterized by $\exp\{v_i\}$. TE has the same properties as in equation 5.2.

Most studies using a production frontier approach have used a two-stage approach. The first stage estimates a production function that is used to calculate technical inefficiencies. The second stage specifies a regression model for the predicted inefficiencies in terms of various explanatory variables and an additive random error. The parameters of the second-stage have been usually estimated by using OLS regression (Battese & Coelli, 1993). The predicted inefficiencies in the first stage are estimated under the assumption that the random errors of inefficiencies are independently and identically distributed (*i.i.d*). In the second stage, however, the independence assumption does not hold. As Kumbhakar, Ghosh, and McGuckin (1991) point out, there are at least two problems. First, the violation of the independence assumption implies that the second-stage parameters are inconsistently estimated.

Second, the use of OLS for estimating the inefficiencies in the second stage does not take consideration of the fact that the dependent variable, inefficiency, is restricted to the 0-1 interval. Consequently, OLS may yield predictions that are inconsistent with this restriction.

Taking consideration of these limitations in the two-stage approach, Kumbhakar, Ghosh, and McGuckin (1991) and Reifschneider and Stevenson (1991), have proposed other models of technical inefficiency in the context of stochastic frontier models. These cross-sectional models provide ways to estimate the parameters of the stochastic frontier and the determinants of inefficiency simultaneously by making appropriate assumptions about the distribution properties of error terms in the model. Battese and Coelli (1995) extended this approach by proposing a stochastic frontier model in which inefficiencies are expressed as specific functions of explanatory variables and in which a panel analysis can be easily applied.

5.3 Econometric Model Specification

5.3.1 Model Specification and Hypothesis

Battese and Coelli (1995) specified a production frontier, choosing a specific functional form. A deterministic frontier adds a one-sided error term ($-u_{it}$) that permits the observation to lie on or below the frontier. If this specification is consistent with the data, one possible estimator is the fixed–effect estimator, where the coefficients of the country dummies can be used to measure the inefficiency. This approach, the deterministic frontier approach, assumes that output and inputs are not subject to random variation and are measured without error. Inefficiency provides the only reason that an agent or country is not operating on the frontier. To allow for random variation as well as inefficiency, a two-part error term ($v_{it} - u_{it}$), where v_{it} represents random variation and $-u_{it}$ represents inefficiency is necessary. With this two-part error term, the model is a stochastic frontier model.

The dissertation follows the example of Adkins, Moomaw and Savvides (2002) and uses transcendent-logarithm functional form:

$$y_{it} = \beta_0 + \beta_1 l_{it} + \beta_2 k_{it} + \beta_3(\frac{1}{2}l_{it}^2) + \beta_4(\frac{1}{2}k_{it}^2) + \beta_5 l_{it} \cdot k_{it} \tag{5.5}$$

where y_{it} is the real value added of industry for country i in time period t, l_{it} the labor input and k_{it} the capital stock in natural log terms, respectively. The translog functional form permits returns to scale to vary by country, while it does not restrict input substitution elasticities to be equal to unity.

The econometric model based on equation (5.5) is:

$$\begin{aligned} y_{it} &= \beta_o + \beta_{1c} l_{it} + \beta_2 k_{it} + \beta_3 (\frac{1}{2} l_{it}^2) + \beta_4 (\frac{1}{2} k_{it}^2) + \beta_5 l_{it} \cdot k_{it} \\ &\tau_1 \cdot Time + \sum_2^{12} \lambda_t \cdot D_t + (v_{it} - u_{it}) \end{aligned} \tag{5.6}$$

where D_t is a country dummy for period t intended to control for unobserved heterogeneity. V_{it} s are random variables that are assumed to be independently and identically distributed ($i.i.d$) N(0, σ_v^2) and independent of the U_{it}, such that

$$U_{it} = z_{it} \cdot \delta + W_{it} \tag{5.7}$$

where the U_{it}'s are non-negative random variables which account for technical inefficiency in *ith* industry production. The U_{it}'s are assumed to be independently distributed and truncated at zero with the distribution of N(m_{it}, σ_U^2).

Technical inefficiencies, the U_{it}'s, are assumed to be a function of a set of explanatory variables, z_{it}'s, and an unknown vector of coefficients, δ. The explanatory variables in the inefficiency model would include variables explaining the extent to which the observations fall short of the corresponding production frontier, $y_{it} = f(x_{it};\beta) \cdot \exp\{v_{it}\} = \exp(x_{it} \cdot \beta + v_{it})$.

The mean inefficiency, m_{it}, is a deterministic function of p explanatory variables:

$$m_{it} = z_{it} \cdot \delta \tag{5.8}$$

where z_{it} is a $p \times 1$ vector of country-specific variables that may vary over time; δ is a $p \times 1$ vector of unknown parameters of the country-specific inefficiency variables with

$$\sigma^2 = \sigma_V^2 + \sigma_U^2 \text{ and } \gamma = \sigma_U^2 / (\sigma_V^2 + \sigma_U^2) \quad (5.9)$$

Following Battese and Corra(1977), the parameter, γ, must lie between 0 and 1.

The parameters (β, δ, σ^2 and γ) of the model are estimated using the maximum likelihood estimator (MLE)[1]. Because γ must lie in the interval zero to one, this range can be searched to provide a good starting value for use in an iterative maximization process such as the Davidson-Fletcher-Powell (DFP) algorithm. Maximum-likelihood estimates are obtained from the computer program FRONTIER 4.1 (Coelli, 1996).

Under the model specification above, the hypothesis ($H_0 : \gamma = 0 \leftrightarrow H_0 : \delta' = 0$) predicts that there are no effects of institution factors on the inefficiency (economic performance) of a specific industry. The null hypothesis ($H_0 : \gamma = 0$) indicates that the technical inefficiency effects are not random. On the other hand, this null hypothesis implies that the technical inefficiency effects are not influenced by the explanatory variables, z_{it}'s in equation (5.7). Therefore the null hypothesis can be expressed by $H_0 : \delta' = 0$, where δ' denotes the vector, δ, the parameters of institution factors. The null hypotheses mean that the explanatory variables in the model have zero coefficients (Battese and Broca, 1996), implying that the institutional variables of the models have no links with the gaps of economic performances of a specific industry across countries and over time. In other words, the null hypothesis, $H_0 : \gamma = 0$, indicates that production frontier is only determined by the production input factors. The stochastic inefficiency

[1] Appendix C describes in detail the derivation procedure and statistics of MLE.

model predicts that the null hypothesis ($H_0 : \gamma = 0$) is rejected at a specific critical level because the rejected hypothesis dictates that inefficiencies are closely connected with institutional factors in interest.

5.3.2 Inefficiency Model

In this dissertation, inefficiencies will be related to institutional factors, similar to those used in Rodrik (2000), Edwards (1998) and Adkins, Moomaw and Savvides (2002). While those studies focus on the inefficiency effects of institutional factors on the economy as a whole across countries, the dissertation examines the effects of institutional factors on economic performance (inefficiency) of a specific industry (ISIC 2-digit industry). In more specific terms, the dissertation estimates parameters of the translog production function of each manufacturing branch and investigates the technical inefficiency effects of institutional factors by determining and testing δ's statistically in the following models.

Frontier Production:

$$\begin{aligned} y_{it} &= \beta_o + \beta_{1c} l_{it} + \beta_2 k_{it} + \beta_3 (\frac{1}{2} l_{it}^2) + \beta_4 (\frac{1}{2} k_{it}^2) + \beta_5 l_{it} \cdot k_{it} \\ &\quad \tau_1 \cdot Time + \sum_2^{12} \lambda_t \cdot D_t + (v_{it} - u_{it}) \end{aligned} \qquad (5.6)$$

Inefficiency Model:

$$\text{M1: } U_{it} = \delta_{EF} \cdot z_{it}^{EF} + \tau_2 \cdot Time + W_{it} \qquad (5.10)$$

$$\text{M2: } U_{it} = \delta_{open} \cdot z_{it}^{open} + \tau_2 \cdot Time + W_{it} \qquad (5.11)$$

$$\text{M3: } U_{it} = \delta_{CR} \cdot z_{it}^{CR} + \tau_2 \cdot Time + W_{it} \qquad (5.12)$$

$$\text{M4: } U_{it} = \delta_{EF} \cdot z_{it}^{EF} + \delta_{open} \cdot z_{it}^{open} + \tau_2 \cdot Time + W_{it} \qquad (5.13)$$

M5: $U_{it} = \delta_{EF} \cdot z_{it}^{EF} + \delta_{CR} \cdot z_{it}^{CR} + \tau_2 \cdot Time + W_{it}$ (5.14)

M6: $U_{it} = \delta_{EF} \cdot z_{it}^{EF} + \delta_{open} \cdot z_{it}^{open} + \delta_{CR} \cdot z_{it}^{CR} + \tau_2 \cdot Time + W_{it}$ (5.15)

The incorporation of the time variable into the first stage of the translog production function allows for growth in Hicks-neutral efficiency. Its inclusion in the second stage of the inefficiency model can determine whether inefficiency is increasing or decreasing over time. Every model in all industries also includes country-specific dummy variables for controlling country heterogeneity. Model 1 provides the estimated coefficient for economic freedom as an institutional factor and Model 2 for market openness and Model 3 for corruption degree. And Models 4 and 5 were regressed on economic freedom and either openness or corruption. Model 6 incorporates the three different institutional factors simultaneously.

5.4 Data on Production Frontier Variables

The sources and calculation of the output and input data for estimating the production frontiers are discussed in Chapter 3. There is, however, some adjustment made in the capital stock calculation. Capital stock is defined as a distributed lag of past investment flows as following formulation:

$$k_{cjt} = \sum (1-\delta)^{n-1} i_{cj,t-n} \tag{3.16}$$

where k_{cjt} is real capital stock. The capital stock in year t does not include the investment of year t, but only up through year $t-1$. δ stands for the depreciation rate ($\delta < 1$). This dissertation follows Harrigan (1997) and assumes $\delta = 0.15$ and $T = 10$.

For example, the capital stock of industry j of the year 1980 can be obtained by:

$$k_{cj1980} = \sum_{i=0}^{79}(1-\delta)^{i} i_{1980-(1+i)} + (1-\delta)^{1980-1970} k_{cj1970} \tag{3.19}$$

In particular, a benchmark capital, k_{cj1970}, can then be calculated in the following way. First, calculate the capital stock series based on the perpetual inventory method. Then take the average capital output ratio for the last five years (1994-1998) and use it to establish a benchmark capital stock for 1970. This is because the capital stock in the 1971 is obviously underestimated thanks to assuming that the capital stock was zero in 1970. By 1994, the initial capital stock of 1970 would be fully depreciated, so the 1994 capital stock is not in error because of the original omission of the 1970 initial stock. As the first step, the capital output ratio in the time period t, $R_t = k_t / y_t$ is derived from the distributed lag of past investment flows. Based on this capital stock series, the average capital output ratio $Avg.R = \overline{R}_{1994-1998}$ is established. The benchmark capital stocks (1970) is derived by using $Avg.R$ as following:

$$\begin{aligned} k_{cjt} &= i_{j,t-1} + (1-\delta)k_{j,t-1} \\ &= i_{j,t-1} + (1-\delta)i_{j,t-2} + (1-\delta)^2 i_{j,t-3} + \dots + (1-\delta)^{\tau} k_{j,1970} \\ &= i_{j,t-1} + (1-\delta)i_{j,t-2} + (1-\delta)^2 i_{j,t-3} + \dots + (1-\delta)^{\tau} AvgR \cdot y_{j,1970} \end{aligned}$$

since $k_{j,1970} = AvgR \cdot y_{j,1970}$

5.5 Institution Factors and Data Descriptions

5.5.1 Economic Freedom

In inefficiency models, expressed by equation (5.11) – (5.16), inefficiencies are modeled as functions of several exogenous institutional factors that might explain efficiency differences across countries. The first factor is a degree of economic freedom experienced by economic agents.

Gwartney et al. (1996) state "that the central elements of economic freedom are personal choice, protection of private property, and freedom of exchange." This statement implies that economic freedom requires the absence of restrictions on the freedom to choose goods, to supply resources and to compete in business and in trade. The greater the degree of economic freedom, the better the expected economic performance.
As Gwartney et al. point out, an index of economic freedom is supposed to measure the extent to which rightly acquired property is protected and economic activities are free to engage in voluntary transactions. Therefore, it is anticipated that the economic freedom index is one of important institutional factors as a determinant of economic efficiency.

Gwartney's economic freedom index, also known as Fraser Institute indicator, is based on 17 different measures and on a scale of 0-10, in which the highest number (10) on each of those measures indicates that a country is completely free and the lowest (0) means that a country is completely unfree. The 17 measures are classified into four broad areas:

I. Money and Inflation: A stable monetary system is necessary for economic agents to respond appropriately to incentives;

II. Government Operations and Regulations: Freedom to decide what is produced and consumed;

III. Takings and Discriminatory Taxation: Freedom to keep what you earn;

IV. Restraints on International exchange: Freedom to exchange with foreigners.

These measures are aggregated into composite indices in three different ways. In the first Index ***Ie***, each component of 17 measures was assigned a weight equal to the inverse of its standard deviation. In the Index ***Is1***, however, the importance of the components derived from a survey under experts in the field of economic freedom. Finally, in the Index ***Is2***, the weighing was based on a survey, but the survey was held under a number of country experts (For more discussion in detail, see Gwartney et al (1996). pp 37-41). These economic freedom indicators are available for 1975, 1980, 1985, 1990, 1995, and 1998. This dissertation use the summary index derived by employing ***Ie*** aggregation.

5.5.2 Market Openness

Market openness as another institutional factor is believed to decide the size of the market. Edwards (1998) argues that higher openness benefits total factor productivity by stating that countries that are more open to the rest of the world have a greater ability to absorb technological advances generated in leading nations. His arguments are based on the fact that larger trade of a country results in greater openness, which facilitates adoption of more efficient techniques of production, followed by faster growth of the total productivity. Similarly, Gwartney et al (2001) suggest "that tariffs, quotas, licenses, marketing restrictions, exchange rate controls, and regulations that limit the movement of capital, are the policies that retard voluntary exchange across national boundaries. Such policies reduce economic freedom".

As an index for market openness, this dissertation uses the Trade Openness Index (TOI)[2], which is designed to measure the degree to which policies interfere with

[2] The TOI index is provided by the Fraser Institute (http://www.freetheworld.com).

international exchange. The TOI has four general components: (a) tariff rates, (b) the black-market exchange rate premium, (c) restrictions on capital movements, and (d) the actual size of the trade sector compared to the expected size (For more discussion in detail, see Gwartney et al (2001): *Economic Freedom of the World: 2001 Annual Report, pp71~).*

The ratings for each of these four components were averaged and used to derive a Trade Openness Index (TOI) for various years during the period from 1980 to 1998. In order to achieve a high TOI rating, a country must have low (and relatively uniform) tariffs, a convertible currency, little restrictions on the mobility of capital, and a large trade sector (given its size and location). Each of these factors implies greater freedom to trade with foreigners. Thus, higher TOI ratings are indicative of greater freedom of exchange across national boundaries.

5.5.3 Corruption

Since the extent to which the infrastructure of an economy favors production or diversion is primarily determined by the government, the reasonable and reliable role of government has been emphasized for promoting and improving economic performances (Jones, 1997). One representative factor, which leads the economy to diversion rather than production, is corruption. Transparency international (TI) defines corruption as the abuse of public office for private gain, and especially focuses on corruption in the public sector. The dissertation analyzes the inefficiency effects of corruption on a specific industry of the economy by using TI Corruption Perceptions Index (CPI) as a proxy variable for corruption.

The TI Corruption Perceptions Index (CPI) is an indicator that seeks to portray perceptions of corruption in countries. The CPI ranks countries in terms of the degree to which corruption is perceived to exist among public officials and politicians. It is a composite index, drawing on 16 different polls and surveys from 8 independent institutions[3]. The CPI incorporates as many reliable and up-to-date sources as possible. One of the drawbacks to this approach is that year-to-year comparisons of a country's score can result from a changed perception of a country's performance or from a changed sample. Index 10 equals an entirely clean country while index 0 equals a country where business transactions are entirely dominated by kickbacks, extortion etc.

[3] See explanatory note of TI Corruption Index: at http://www.transparency.org/cpi~

5.6 Analysis of Empirical Results

This part of the dissertation investigates the influence of institutions on economic efficiency in the manufacturing sector and selected 2-digit ISIC industries of 12 OECD countries. The approach is to estimate a stochastic production frontier and an associated inefficiency model using a maximum likelihood procedure. A translog frontier with Hicks-neutral efficiency is estimated. Institutional factors — economic freedom, economic openness, and corruption — and time are taken as the determinants of inefficiency. Strong evidence supporting the expected effects of institutions on efficiency is found for the manufacturing sector as a whole, whereas somewhat weaker support is found for the manufacturing branches. The results of this dissertation, however, provide somewhat different explanations on those relationships. Briefly describing the estimated results, inefficiencies of the manufacturing sector as a whole or a specific industry-level (ISIC 2-digit industry) are decreased by higher level of economic freedom, economic openness, and lower degree of corruption. These empirics dictate that the technical efficiencies of the manufacturing industries depend on the economic environment, expressed by the institutional factors. Specifically, ***Table 5.1 – Table 5.10*** provide the results of ML estimation by industry. The results are obtained from panel data on 12 OECD country-samples covering 5 time periods of 1980, 1985, 1990, 1995 and 1998.

Prior to examining the empirical results, several comments are appropriate. First, the coefficient of the time variable[4] in the production function model represents growth in

[4] Time variables are expressed by 1, 2, 3, 4 and 4.6, in order to represent the time periods, 1980-1985,

Hicks-neutral efficiency. If technology is improving over time, it will have a positive coefficient. In interpreting the coefficient, one must recall that the growth rates are for five-year increments. Second, inefficiency is expected to decrease with increases in economic freedom and openness and decreases in corruption. Third, the coefficient of the time variable in the inefficiency model gives the trend in inefficiency.

Note that the estimate, $\hat{\sigma}^2$, is representing for $\sigma^2 = \sigma_V^2 + \sigma_U^2$ in equation (5.10) and the estimate of $\hat{\gamma}$ is an inefficiency indicator. Intuitively, $\hat{\gamma} \cong 0$, means that deviations from the frontier due to random effects — the two-sided error term — is large, approaching 100 percent, relative to deviations due to inefficiency—the one-sided error term. In fact, $\hat{\gamma} \cong 0$ implies that random error in the model comes from the production function. Conversely, $\hat{\gamma} \cong 1$ implies that the deviations from the frontier come largely (exclusively) from the technical inefficiency—the one-sided error term. Therefore, $\hat{\gamma} > 0$ is necessary for the existence of inefficiency (Battese and Coelli, 1993; Coelli et al, 1998).

5.6.1 Manufacturing Sector

Table 5.1 represents the effects of institutional factors in the manufacturing sector as a whole. Each model for the manufacturing sector shows that the coefficients for the institutional factors are statistically different from zero, implying that the stochastic production frontier approach is appropriate. Model 1, Model 2 and Model 3 provide that each institutional factor is a highly significant determinant of the inefficiency of the manufacturing sector, respectively. In particular, it should be noted that even when the

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1985-1990, 1990-1995 and 1995-1998, respectively.

inefficiency is explained by two or all the institutional factors (Model 4, Model 5 and Model 6), their coefficients are statistically reliable at the 1 % or 5 % critical level. The negative and significant coefficients of economic freedom in all models statistically confirm that increases in economic freedom reduce the inefficiency.

For market openness, Model 2, Model 4 and Model 6 show a significant coefficient in the inefficiency function indicating that increases in market scale reduce inefficiency. When the inefficiency function is explained by only market openness (Model 2), the coefficient of market openness, -0.0872 is statistically significant with a t-ratio of -5.64. Furthermore, even when market openness is considered with other institutional factors (Model 4 and Model 6), the estimates for market openness are theoretically plausible (negative relationship with inefficiency) and statistically significant at the 1% (Model 4) or 5 % (Model 6) critical level.

Decreases in corruption (increases in the index) have a negative effect on technical inefficiency. Its coefficients in all models are negative and statistically significant. Even when corruption is simultaneously explained with other institutional factors (Model 5 and Model 6), the empirics show the reduced corruption degree is associated with less inefficiency.

In brief, the coefficients on economic freedom, market openness and corruption are statistically significantly different from zero in all models. And when all the institutional factors (Model 6) or two of them (Model 4 and Model 5) are included in the same model, the coefficients are negative and statistically significant at 5 % critical level. These empirics strongly support the hypothesis that the institutional environment determines economic performance in terms of technical inefficiencies in the manufacturing sector.

Table 5.1: MLE of the Production Frontier and Determinants of Inefficiency ISIC 3: Manufacturing Sector

Variable	Parameter	M:1	M:2	M:3	M:4	M:5	M:6
Production:							
Constant	β_0	-5.9762	-2.6054	-2.0628	-3.0112	-2.8781	-2.8812
		(-5.06)	(-2.63)	(-2.44)	(-3.04)	(-2.91)	(-2.95)
ln(L)	β_1	4.2085	3.6924	4.4840	3.5871	3.3838	3.7885
		(9.10)	(4.55)	(8.01)	(7.11)	(4.37)	(5.76)
ln(K)	β_2	0.2454	-0.3018	-0.6794	-0.1621	0.1135	-0.1599
		(1.42)	(-0.60)	(-2.11)	(-0.45)	(0.24)	(-0.40)
$0.5[\ln(L)]^2$	β_3	-0.6129	-0.5690	-0.7717	-0.5550	-0.5426	-0.6304
		(-9.50)	(-3.38)	(-12.97)	(-6.84)	(-3.43)	(-4.79)
$0.5[\ln(K)]^2$	β_4	-0.0100	0.0305	0.0226	0.0237	-0.0237	0.0070
		(-0.50)	(0.68)	(0.32)	(0.59)	(-0.55)	(0.19)
$\ln(L)\cdot\ln(K)$	β_5	0.0324	0.0614	0.1110	0.0571	0.0714	0.0771
		(1.70)	(1.05)	(2.39)	(1.34)	(1.31)	(1.67)
Time	τ_1	0.0328	0.0439	0.0812	0.0245	0.0570	0.0269
		(4.05)	(2.53)	(1.69)	(2.02)	(3.92)	(2.26)
Country Dummy		yes	yes	yes	yes	yes	yes
Inefficiencies:							
Constant	δ_0	1.5211	0.7880	0.8235	0.8447	1.1421	1.2255
		(10.63)	(7.52)	(8.51)	(5.97)	(5.71)	(6.10)
E. Freedom	δ_1	-0.1968			-0.0377	-0.0795	-0.0842
		(-10.63)			(-1.44)	(-3.15)	(-3.70)
Openness	δ_2		-0.0872		-0.0570		-0.0365
			(-5.64)		(-3.30)		(-2.46)
Corruption	δ_3			-0.0938		-0.0563	-0.0268
				(-5.84)		(-4.54)	(-2.47)
Time	τ_2	-0.0514	0.0068	0.0014	-0.0053	-0.0141	0.0054
		(-3.44)	(0.43)	(0.34)	(-0.44)	(-0.91)	(0.34)
Variance	$\hat{\sigma}^2$	0.0223	0.0057	0.0071	0.0059	0.0084	0.0073
		(8.26)	(4.79)	(14.54)	(5.52)	(8.64)	(7.48)
Ineff. Indicator	$\hat{\gamma}$	0.9999	1.0000	1.0000	1.0000	1.0000	1.0000
		(1932.69)	(515.06)	(21994.32)	(130.41)	(330.05)	(1576.64)
Log Likelihood		86.5194	77.1613	80.7027	79.8627	78.3982	80.4987
LR Test Statistics ($H_0 : \delta' = 0$)		28.3227	9.6066	16.6893	15.0094	12.0804	16.2814

Note : 1) The estimators were obtained by using Coelli's computer program (Frontier Version 4.1).
2) All models were regressed on data sets of 12 OECD countries over 1980, 1985, 1990, 1995, and 1998.
3) The numbers in parenthesis indicate t-values.

The coefficients of the time variable in the production function are positive and statistically significant at 10 % critical level (Model 3), 5 % level (Model 2, Model 4 and Model 6) and 1 % level (Model 1 and Model 5). These coefficients suggest that Hicks-neutral efficiency is growing at from 0.5 to 1.6 percent per year.

The coefficients of the time variable in the inefficiency models are insignificant except for Model 1. Model 1 says that increases in economic freedom reduce inefficiency and that there is a negative trend in inefficiency. Adding either openness or corruption or both to the model results in significant coefficients for the added variables and eliminates the statistical significance of time.

$\hat{\gamma}$-values range 0.9999 (Model 1) to 1.0000 (other models). The high value of $\hat{\gamma}(\cong 1)$ indicates that the stochastic impacts of the model are attributed to technical inefficiency rather than random errors. The highly significant $\hat{\gamma}$ indicates that the stochastic frontier approach is appropriate for the manufacturing sector as a whole. Furthermore, LR test statistics[5] in all models dictates that the hypothesis, $H_0 : \delta' = 0$, is rejected at 5 % critical level. At 5% critical level, chi-square statistics are 7.77 for Model 1 Model 2 and Model 3, since $H_0 : \delta' = \delta_0 = \delta_1 = \tau_2 = 0$ or $H_0 : \delta' = \delta_0 = \delta_2 = \tau_2 = 0$ or $H_0 : \delta' = \delta_0 = \delta_3 = \tau_2 = 0$. Chi-square statistics for Model 4 and Model 5 are 9.24, based on the hypothesis, $H_0 : \delta' = \delta_0 = \delta_1 = \delta_2 = \tau_2 = 0$ or $H_0 : \delta' = \delta_0 = \delta_1 = \delta_3 = \tau_2 = 0$. For Model 6, chi-square statistics is 10.64 under the hypothesis, work on spacing $H_0 : \delta' = \delta_0 = \delta_1 = \delta_2 = \delta_3 = \tau_2 = 0$. This rejection of the null hypothesis dictates that a

[5] The likelihood ratio test statistic is calculated as λ = -2[log(likelihood (H_0) - log(likelihood (H_1))] and has approximately a mixed chi-square distribution with degrees of freedom equal to the number of parameters assumed to be equal to zero in the null hypothesis, H_0 (for discussion in detail, see Battese and Coelli (1993)).

stochastic frontier exists and the inefficiency (economic performance) of the manufacturing sector as a whole is determined by the institutional factors, which are represented by economic freedom, market openness and corruption degree.

5.6.2 Food Products, Beverages and Tobacco

Table 5.2 represents the effects of institutional factors in ISIC 31- Food Products, Beverages and Tobacco - a branch of the manufacturing sector. In Model 1 and 3-5, the null hypothesis that parameters of the inefficiency are jointly equal to zero is rejected at the 5% critical value. It is not rejected for Models 2 and 6. Unlike the aggregate manufacturing sector, some of the institutional variables are not significant.

The analysis of the results is restricted to those models for which the inefficiency component exists. Economic freedom has the predicted negative coefficient, significant at the 1% critical level (Model 1 and Model 4) and 10 % level (Model 5). Corruption is significant at the 1% level in Models 3 and 5, but openness is never significant. Time is significant at a 1% critical value with a positive coefficient in Model 1 and 4. If economic freedom is controlled, but not corruption, the time trend is one of increasing inefficiency. In Model 3 and 5, corruption is significant with the expected negative sign; in these models time is not significant. The preferred model is Model 5, which finds that both increases in freedom and decreases in corruption reduce inefficiency. Once corruption is controlled, there is no time trend in inefficiency. The time trend in the production function for the relevant models suggest that Hicks-neutral efficiency is growing between 1.1 and 1.4 percent per year.

Table 5.2: MLE of the Production Frontier and Determinants of Inefficiency ISIC 31: Food Products, Beverages and Tobacco

Variable	Parameter	M:1	M:2	M:3	M:4	M:5	M:6
Production:							
Constant	β_0	0.2103	-5.8915	-1.7941	-2.4058	-1.6330	-5.0897
		(0.10)	(-6.00)	(-0.41)	(-0.53)	(-0.33)	(-4.53)
ln(L)	β_1	2.2936	2.6115	2.3016	3.0911	2.2775	3.7080
		(2.31)	(2.97)	(1.32)	(1.87)	(1.37)	(4.25)
ln(K)	β_2	0.7440	1.8363	1.1535	0.8827	1.0850	0.9241
		(1.42)	(3.49)	(1.60)	(1.51)	(1.67)	(1.70)
$0.5[\ln(L)]^2$	β_3	-0.7478	-0.5923	-0.7483	-0.8430	-0.7442	-0.9028
		(-3.74)	(-0.75)	(-2.63)	(-3.24)	(-2.91)	(-3.96)
$0.5[\ln(K)]^2$	β_4	-0.1760	-0.2204	-0.2425	-0.1809	-0.2289	-0.1021
		(-2.59)	(-0.88)	(-2.98)	(-2.53)	(-2.79)	(-1.44)
$\ln(L)\cdot\ln(K)$	β_5	0.2053	0.0848	0.2281	0.1793	0.2252	0.1024
		(3.07)	(0.20)	(2.58)	(2.23)	(2.69)	(1.39)
Time	τ_1	0.0555	0.0634	0.0761	0.0660	0.0746	-0.0063
		(2.99)	(2.56)	(4.65)	(2.54)	(4.14)	(-0.22)
Country Dummy		yes	yes	yes	yes	yes	yes
Inefficiencies:							
Constant	δ_0	4.1097	0.0668	1.2748	4.4708	2.1890	0.9879
		(2.84)	(0.04)	(3.16)	(2.80)	(2.66)	(3.18)
E. Freedom	δ_1	-0.1968			-0.7374	-0.2319	-0.3568
		(-2.78)			(-2.92)	(-1.64)	(-2.87)
Openness	δ_2		-0.0113		-0.0570		0.0480
			(-0.90)		(-0.86)		(0.81)
Corruption	δ_3			-0.1674		-0.1112	0.1417
				(-2.97)		(-2.05)	(2.84)
Time	τ_2	0.2401	0.0134	-0.0490	0.2927	0.0760	-0.0100
		(3.88)	(0.16)	(-0.90)	(2.47)	(0.96)	(-0.24)
Variance	$\hat{\sigma}^2$	0.0409	0.0085	0.0238	0.0526	0.0226	0.0164
		(2.97)	(1.26)	(2.04)	(2.79)	(2.00)	(7.04)
Ineff. Indicator	$\hat{\gamma}$	0.9418	0.0543	0.9138	0.9588	0.8991	0.6793
		(29.97)	(0.06)	(11.01)	(33.31)	(12.70)	(6.33)
Log Likelihood		66.5875	59.4478	66.0719	66.8183	68.2341	63.6504
LR Test Statistics ($H_0 : \delta' = 0$)		14.8254	0.5461	13.7943	15.2870	18.1187	8.9513

Note : 1) The estimators were obtained by using Coelli's computer program (Frontier Version 4.1).
2) All models were regressed on data sets of 12 OECD countries over 1980, 1985, 1990, 1995, and 1998.
3) The numbers in parenthesis indicate t-values.

5.6.3 Textiles, Textile Products, Leather & Footwear

Table 5.3 presents the results for ISIC 32- Textiles, Textile Products, Leather and Footwear. The LR (likelihood ratio) statistic indicates that the null hypothesis that the coefficients of the inefficiency model jointly equal zero is rejected at the 5 % critical level for Models 1, 3, and 4. The rejected null hypothesis allows the conclusion that a stochastic frontier exists and that institutional factors and time are jointly important in explaining the efficiency of the industry.

The inefficiency indicator $\hat{\gamma}$ is singly significant based on the t statistic in these models and model 5, indicating the existence of the stochastic frontier. In Model 1 economic freedom takes a negative coefficient that is about the same size as its standard error; in Model 3 corruption has a positive coefficient, indicating that greater corruption is associated with less technical inefficiency. In Model 4, economic freedom has the expected negative coefficient significant at the 5 % critical level. In these models, inefficiency is falling over time, holding the other variables constant. Thus, the institutional variables for this industry are less successful in explaining inefficiency.

The three significant models have a negative and significant coefficient for time , indicating that inefficiency decreased over time (not significant for Model 5 and Model 6). The positive coefficient for corruption and its relatively low standard error raises concern. Finally, economic freedom is only significant in one of the two models in which it appears. The coefficients of time in the production function are statistically significant and negative in the models where the inefficiency results are significant. This estimate of decreasing Hicks-neutral efficiency for this industry, while surprising, is not unique; other studies have reported this result for other industries.

Table 5.3: MLE of the Production Frontier and Determinants of Inefficiency
ISIC32: Textiles, Textile Products, Leather& Footwear

Variable	Parameter	M:1	M:2	M:3	M:4	M:5	M:6
Production:							
Constant	β_0	2.5304	4.1213	4.6084	3.3582	3.9610	4.1143
		(2.39)	(2.95)	(3.99)	(1.61)	(3.97)	(4.28)
ln(L)	β_1	0.8834	1.0763	0.8443	1.0261	1.7687	1.0143
		(2.40)	(2.40)	(1.89)	(3.27)	(3.43)	(1.90)
ln(K)	β_2	0.6240	0.1019	0.0159	0.3996	-0.1422	0.1461
		(2.00)	(0.24)	(0.10)	(0.64)	(-0.39)	(0.41)
$0.5[\ln(L)]^2$	β_3	-0.3137	-0.1704	-0.2183	-0.2386	-0.4750	-0.2531
		(-3.90)	(-1.32)	(-1.97)	(-1.90)	(-3.98)	(-2.08)
$0.5[\ln(K)]^2$	β_4	-0.1231	-0.0312	-0.0067	-0.0647	-0.0262	-0.0668
		(-2.24)	(-0.36)	(-0.19)	(-0.53)	(-0.38)	(-1.01)
$\ln(L)\cdot\ln(K)$	β_5	0.1500	0.0661	0.0941	0.0900	0.1288	0.1200
		(3.04)	(0.80)	(2.55)	(0.96)	(1.63)	(1.59)
Time	τ_1	-0.0584	0.0507	-0.0568	-0.0836	-0.0036	0.0378
		(-2.45)	(1.99)	(-12.78)	(-4.95)	(-0.11)	(0.91)
Country Dummy		yes	yes	yes	yes	yes	yes
Inefficiencies:							
Constant	δ_0	0.7978	0.8088	-0.3438	1.2288	-0.6483	-0.5974
		(3.32)	(3.61)	(-2.36)	(2.24)	(-1.50)	(-0.77)
E. Freedom	δ_1	-0.1968			-0.1840	-0.1152	0.0208
		(-1.09)			(-2.14)	(-1.81)	(0.29)
Openness	δ_2		-0.1254		0.1056		-0.0872
			(-3.42)		(1.26)		(-1.45)
Corruption	δ_3			0.0980		0.1917	0.1416
				(4.27)		(2.90)	(1.21)
Time	τ_2	-0.1718	0.0657	-0.1414	-0.3520	-0.0147	-0.0115
		(-5.01)	(2.03)	(-6.53)	(-4.25)	(-0.45)	(-0.22)
Variance	$\hat{\sigma}^2$	0.0343	0.0094	0.0205	0.0573	0.0181	0.0131
		(11.88)	(4.62)	(5.98)	(6.45)	(5.19)	(4.04)
Ineff. Indicator	$\hat{\gamma}$	1.0000	0.1170	1.0000	1.0000	0.7364	0.5380
		(920318.10)	(0.70)	(6416.69)	(4619.09)	(3.77)	(1.41)
Log Likelihood		63.2881	56.0887	75.7878	62.3601	57.0637	57.1264
LR Test Statistics ($H_0 : \delta' = 0$)		20.4639	6.0650	45.4633	18.6079	8.0151	8.1403

Note : 1) The estimators were obtained by using Coelli's computer program (Frontier Version 4.1).
2) All models were regressed on data sets of 12 OECD countries over 1980, 1985, 1990, 1995, and 1998.
3) The numbers in parenthesis indicate t-values.

5.6.4 Wood, Products of Wood and Cork

Table 5.4 provides the effects of institutional factors in ISIC 33- Wood, Products of Wood and Cork. Each model for the industry shows that the coefficients for the institutional factors are statistically different from zero, implying that the negative and significant coefficients (5 % critical level in Models 1 and 4 and 10 % critical level in Model 5) of economic freedom in all models (Except Model 6) are as expected. Market openness and corruption are significant (5 % critical value) in all models in which they appear.

The LR statistic for the null hypothesis that all parameters of the inefficiency model jointly equal 0 is rejected for all models. Similarly, the t-statistic for $\hat{\gamma}$ shows that it is statistically significant. Thus, the stochastic production frontier with a jointly significant inefficiency model is appropriate in all cases.

The results for this industry are similar to those for the aggregate manufacturing with only qualitative differences. Economic freedom, however, is not significant in the equation with the other two institutional variables and the indication of decreasing inefficiency over time in the model that includes all three institutional factors.

The insignificant coefficients of time in the production function indicate that Hicks-neutral efficiency is not changing over time.

5.6.5 Pulp, Paper, Paper Products, Printing and Publishing

As ***Table 5.5*** shows, the results for ISIC 34--Pulp, Paper, Paper Products, Printing and Publishing—are similar to those for ISIC 33 and the overall manufacturing sector. The null hypotheses that the coefficients of the inefficiency model jointly equal 0 and that

Table 5.4: MLE of the Production Frontier and Determinants of Inefficiency ISIC33: Wood, Products of Wood and Cork

Variable	Parameter	M:1	M:2	M:3	M:4	M:5	M:6
Production:							
Constant	β_0	-3.5383	-3.4364	-3.2901	-3.4899	-3.2842	-3.8140
		(-1.96)	(-2.00)	(-3.28)	(-2.19)	(-2.17)	(-2.81)
ln(L)	β_1	0.6732	0.7569	0.6938	0.7414	0.6890	0.8162
		(1.51)	(1.65)	(1.53)	(1.48)	(1.55)	(1.65)
ln(K)	β_2	1.9793	2.0079	1.9825	1.9736	1.9318	2.0551
		(4.37)	(4.60)	(6.33)	(4.63)	(4.45)	(5.95)
$0.5[\ln(L)]^2$	β_3	0.0725	-0.0562	-0.0893	-0.0775	-0.0829	-0.1051
		(-0.60)	(-0.45)	(-0.70)	(-0.60)	(-0.65)	(-0.82)
$0.5[\ln(K)]^2$	β_4	-0.2047	-0.1976	-0.2100	-0.2019	-0.2017	-0.2156
		(-3.20)	(-3.12)	(-4.22)	(-3.25)	(-3.27)	(-4.02)
$\ln(L)\cdot \ln(K)$	β_5	0.0412	0.0136	0.0432	0.0325	0.0435	0.0357
		(1.04)	(0.33)	(1.13)	(0.78)	(1.17)	(0.90)
Time	τ_1	0.0065	0.0133	0.0058	0.0120	0.0078	0.0113
		(0.47)	(0.98)	(0.38)	(0.88)	(0.49)	(0.83)
Country Dummy		yes	yes	yes	yes	yes	yes
Inefficiencies:							
Constant	δ_0	5.6432	3.6294	2.0715	6.4694	3.8594	4.3474
		(1.77)	(1.83)	(2.38)	(2.01)	(2.17)	(2.11)
E. Freedom	δ_1	-0.1968			-0.6298	-0.4015	-0.0916
		(-1.65)			(-1.73)	(-1.55)	(-0.81)
Openness	δ_2		-0.5845		-0.4229		-0.3951
			(-1.70)		(-1.94)		(-1.57)
Corruption	δ_3			-0.2599		-0.1875	-0.1619
				(-1.74)		(-2.08)	(-2.20)
Time	τ_2	-0.1668	-0.2816	-0.4580	-0.0285	-0.3325	-0.2113
		(-1.69)	(-1.73)	(-1.60)	(-0.49)	(-2.55)	(-3.03)
Variance	$\hat{\sigma}^2$	0.1627	0.1329	0.0985	0.1166	0.1228	0.0803
		(1.74)	(1.81)	(1.49)	(2.08)	(1.80)	(2.00)
Ineff. Indicator	$\hat{\gamma}$	0.9815	0.9719	0.9612	0.9682	0.9707	0.9479
		(74.73)	(46.27)	(33.56)	(51.34)	(48.68)	(30.25)
Log Likelihood		54.7997	54.7544	54.9017	56.3778	55.4804	57.2508
LR Test Statistics ($H_0 : \delta' = 0$)		28.0259	27.9352	28.2298	31.1821	29.3872	32.9281

Note : 1) The estimators were obtained by using Coelli's computer program (Frontier Version 4.1).
2) All models were regressed on data sets of 12 OECD countries over 1980, 1985, 1990, 1995, and 1998.
3) The numbers in parenthesis indicate t-values.

the stochastic frontier does not exist ($\hat{\gamma}$ = 0) are rejected for all models. The coefficients of the institutional variables take a negative sign in all models. Economic freedom has the correct negative sign and is significant in Models 1 and 4 at the 1 % critical level. It is not significant when combined with corruption or with corruption and openness.

Openness is also significant at the 1 % critical level when combined with economic freedom and economic freedom and corruption. It is not significant in Model 2, where it is the only institutional variable. Finally, corruption is significant with the expected sign whether by itself or in combination with the other institutional variables. The coefficients of time in the inefficiency function are generally positive, suggesting that inefficiency is increasing over time, institutional factors held constant. The time coefficients in the production function are positive and statistically significant (1 % critical level) in all models except Model 2, which appears to be an aberration. This suggests that there exist stable and strong benefits from technology improvement in the production function, with a growth rate of 3 to 3.7 percent per year.

5.6.6 Chemical, Rubber, Plastics and Fuel Products

Table 5.6 shows that for 5 of the 6 models for ISIC 35(Chemical, Rubber, Plastics and Fuel Products industry) the two null hypotheses of no efficiency frontier and zero coefficients for all of the parameters of the inefficiency model are rejected. The nulls are not rejected for Model 5. Models 1 through 3 with one institutional variable and time have significant, negative coefficients for economic freedom and for corruption (5 % critical value), but a positive coefficient for openness that is more than twice its standard error. Neither institution variable in Model 4 (freedom and openness) has a significantly

Table 5.5: MLE of the Production Frontier and Determinants of Inefficiency ISIC 34: Pulp, Paper, Paper Products, Printing and Publishing

Variable	Parameter	M:1	M:2	M:3	M:4	M:5	M:6
Production:							
Constant	β_0	-3.2683	-2.7922	-3.7545	-3.7095	-3.9891	-4.1563
		(-3.23)	(-2.87)	(-1.37)	(-3.91)	(-1.34)	(-2.03)
ln(L)	β_1	1.5607	-3.6645	1.4809	2.7086	1.5830	1.9616
		(2.15)	(-4.43)	(1.27)	(3.79)	(1.21)	(1.97)
ln(K)	β_2	1.4834	2.4962	1.7197	1.0343	1.7100	1.5410
		(3.78)	(8.19)	(4.06)	(2.88)	(4.10)	(3.99)
$0.5[\ln(L)]^2$	β_3	-0.1991	0.9145	-0.1497	-0.4361	-0.1711	-0.2256
		(-0.88)	(1.08)	(-0.54)	(-2.01)	(-0.57)	(-0.92)
$0.5[\ln(K)]^2$	β_4	-0.1955	-0.2819	-0.2287	-0.1433	-0.2287	-0.2021
		(-4.98)	(-1.50)	(-5.31)	(-4.01)	(-5.40)	(-5.46)
$\ln(L)\cdot\ln(K)$	β_5	0.0648	0.0675	0.0562	0.0594	0.0580	0.0445
		(1.29)	(0.16)	(1.11)	(1.18)	(1.13)	(0.96)
Time	τ_1	0.1459	-2.3868	0.1568	0.1428	0.1576	0.1715
		(7.12)	(-6.11)	(8.66)	(6.84)	(8.55)	(9.37)
Country Dummy		yes	yes	yes	yes	yes	yes
Inefficiencies:							
Constant	δ_0	0.7976	-0.0708	0.7258	1.0308	0.8606	1.5726
		(4.11)	(-0.08)	(2.29)	(6.66)	(1.06)	(2.87)
E. Freedom	δ_1	-0.1968			-0.0851	-0.0282	-0.0513
		(-3.85)			(-2.43)	(-0.18)	(-0.71)
Openness	δ_2		-0.0286		-0.0722		-0.1564
			(-0.03)		(-4.10)		(-3.06)
Corruption	δ_3			-0.1347		-0.1329	-0.0509
				(-2.13)		(-1.92)	(-2.61)
Time	τ_2	0.0813	-0.4752	0.0135	0.0805	0.0294	0.1275
		(3.19)	(-2.20)	(0.29	(3.81)	(0.29)	(2.45)
Variance	$\hat{\sigma}^2$	0.0081	16.2076	0.0144	0.0092	0.0154	0.0082
		(6.78)	(40.76)	(1.89)	(7.87)	(1.43)	(2.23)
Ineff. Indicator	$\hat{\gamma}$	1.0000	1.0000	0.7773	1.0000	0.7994	0.7733
		(9.985)	(700605.3)	(5.08)	(321.20)	(4.21)	(5.02)
Log Likelihood		72.7901	-73.3154	74.6368	77.0625	74.6541	79.5127
LR Test Statistics ($H_0 : \delta' = 0$)		9.2900	135.3835	12.9835	17.8349	13.0180	22.7352

Note : 1) The estimators were obtained by using Coelli's computer program (Frontier Version 4.1).
2) All models were regressed on data sets of 12 OECD countries over 1980, 1985, 1990, 1995 and 1998.
3) The numbers in parenthesis indicate t-values.

Table 5.6: MLE of the Production Frontier and Determinants of Inefficiency ISIC35: Chemical, Rubber, Plastics and Fuel Products

Variable	Parameter	M:1	M:2	M:3	M:4	M:5	M:6
Production:							
Constant	β_0	11.4796	12.7520	9.6007	12.0688	9.4966	9.8666
		(10.41)	(26.80)	(9.78)	(10.25)	(9.66)	(17.43)
ln(L)	β_1	2.5989	0.7797	1.4182	1.9714	1.4957	1.7264
		(3.10)	(0.63)	(1.62)	(2.56)	(1.69)	(2.23)
ln(K)	β_2	-2.1472	-1.6560	-1.1497	-1.9572	-1.2028	-1.3790
		(-4.64)	(-2.24)	(-2.33)	(-4.92)	(-2.40)	(-3.92)
$0.5[\ln(L)]^2$	β_3	-1.3105	-0.9361	-0.7180	-0.9803	-0.5401	-0.7594
		(-3.80)	(-1.08)	(-0.97)	(-3.38)	(-0.67)	(-2.16)
$0.5[\ln(K)]^2$	β_4	0.0954	0.0505	0.0641	0.1360	0.1099	0.0725
		(2.17)	(0.89)	(0.33)	(3.19)	(0.51)	(1.33)
$\ln(L)\cdot\ln(K)$	β_5	0.3858	0.3886	0.2274	0.2757	0.1409	0.2364
		(3.81)	(1.37)	(0.63)	(3.12)	(0.36)	(1.94)
Time	τ_1	0.1100	0.0723	0.0280	0.0636	0.0282	0.0588
		(7.21)	(15.13)	(1.37)	(3.30)	(0.26)	(2.16)
Country Dummy		yes	yes	yes	yes	yes	yes
Inefficiencies:							
Constant	δ_0	-2.0321	-1.8693	0.7577	-1.7495	0.0781	0.7649
		(-4.18)	(-2.63)	(1.26)	(-3.07)	(0.08)	(0.84)
E. Freedom	δ_1	-0.1968			0.1501	0.0747	-0.0002
		(-2.34)			(1.76)	(0.20)	(0.00)
Openness	δ_2		0.0995		-0.0577		-0.0494
			(2.72)		(-0.97)		(-0.70)
Corruption	δ_3			-0.1030		-0.0835	-0.0852
				(-2.27)		(-0.51)	(-2.92)
Time	τ_2	0.2559	0.2951	0.0318	0.2895	0.0097	0.1007
		(6.38)	(7.78)	(0.35)	(5.39)	(0.02)	(1.70)
Variance	$\hat{\sigma}^2$	0.0447	0.0698	0.0256	0.0483	0.0247	0.0271
		(7.80)	(1.95)	(5.58)	(7.56)	(1.37)	(20.63)
Ineff. Indicator	$\hat{\gamma}$	1.0000	1.0000	0.9743	0.9999	0.8005	0.9765
		(122694.82)	(2957.36)	(5.31)	(311.64)	(0.75)	(3.30)
Log Likelihood		54.7111	60.0100	46.9035	52.6782	44.0501	49.2693
LR Test Statistics ($H_0 : \delta' = 0$)		26.3905	36.9882	10.7753	22.3246	5.0684	15.5068

Note : 1) The estimators were obtained by using Coelli's computer program (Frontier Version 4.1).
2) All models were regressed on data sets of 12 OECD countries over 1980, 1985, 1990, 1995 and 1998.
3) The numbers in parenthesis indicate t-values.

negative coefficient. In Model 6 the three institutional variables have negative coefficients but only one—for corruption—is statistically significant. In 4 of the five models, the residual time trend takes a positive coefficient, significant at the critical value of 0.10 percent or less. This indicates that holding institutional factors constant, inefficiency is increasing in this industry. The coefficient of time in the production function is generally positive and significant, with the significant coefficients indicating Hicks-neutral efficiency growth of from 0.5 to 2.2 percent per year.

5.6.7 Other Non-Metallic Mineral Products

Table 5.7 shows that only Models 1 and 3 reject both null hypotheses for industry ISIC 36 – Other Non-Metallic Mineral Products. In addition, the inefficiency indicator, γ, indicates that the stochastic frontier with inefficiency effects exist in Models 5 and 6. In Models 1 and 3 the institutional variables (economic freedom and corruption) are significant with the predicted negative sign, and the time coefficients are not significant. With either institutional variable, any inefficiency time trend becomes insignificant. Although in Models 5 and 6 the null hypothesis that all of inefficiency model's coefficients jointly equal zero cannot be rejected, testing the coefficients individually shows that corruption has the predicted negative coefficient, significant at a 1 percent critical value. In this model, market openness has a positive coefficient with a relatively small standard error. Economic freedom has a negative coefficient that falls short of significance using a 10 percent critical value. Finally, in this model, time's coefficient is negative, depicting a residual trend of decreasing inefficiency.

The time effects in the production function are positive and statistically significant at

Table 5.7: MLE of the Production Frontier and Determinants of Inefficiency ISIC36: Other Non-Metallic Mineral Products

Variable	Parameter	M:1	M:2	M:3	M:4	M:5	M:6
Production:							
Constant	β_0	3.3340	5.6818	3.3969	5.6858	2.7041	4.1634
		(3.39)	(3.50)	(3.09)	(5.12)	(2.56)	(4.28)
ln(L)	β_1	0.1498	0.1655	0.6786	-0.0100	0.8539	0.8668
		(0.37)	(0.21)	(1.42)	(-0.01)	(1.29)	(0.97)
ln(K)	β_2	1.0308	0.1953	0.7621	0.4194	0.9117	0.5463
		(4.48)	(0.40)	(2.89)	(1.03)	(4.16)	(1.16)
$0.5[\ln(L)]^2$	β_3	0.1871	0.2517	0.0708	0.2543	0.0377	0.1271
		(3.55)	(1.14)	(0.61)	(1.20)	(0.22)	(0.54)
$0.5[\ln(K)]^2$	β_4	-0.0504	0.0563	-0.0045	0.0363	-0.0208	0.0308
		(-1.29)	(0.86)	(-0.11)	(0.62)	(-0.68)	(0.39)
$\ln(L)\cdot\ln(K)$	β_5	-0.0770	-0.0820	-0.0945	-0.0861	-0.1044	-0.1343
		(-2.05)	(-1.09)	(-1.49)	(-1.30)	(-1.69)	(-1.49)
Time	τ_1	0.0495	0.0720	0.0631	0.0316	0.0591	0.0514
		(8.83)	(4.03)	(8.33)	(1.78)	(20.55)	(2.46)
Country Dummy		yes	yes	yes	yes	yes	yes
Inefficiencies:							
Constant	δ_0	1.2469	-0.9518	0.7954	0.3516	0.7971	0.5403
		(5.88)	(-1.49)	(4.06)	(1.27)	(2.34)	(1.45)
E. Freedom	δ_1	-0.1968			-0.0643	0.0132	-0.0834
		(-5.28)			(-1.57)	(0.28)	(-1.25)
Openness	δ_2		0.1303		0.0474		0.1236
			(1.48)		(1.45)		(1.99)
Corruption	δ_3			-0.0935		-0.1137	-0.0742
				(-2.57)		(-2.69)	(-2.79)
Time	τ_2	0.0336	-0.0331	-0.0106	-0.0259	-0.0246	-0.0613
		(1.07)	(-1.01)	(-0.37)	(-1.16)	(-0.49)	(-1.99)
Variance	$\hat{\sigma}^2$	0.0406	0.0093	0.0174	0.0106	0.0204	0.0147
		(5.14)	(4.57)	(14.92)	(5.26)	(1.66)	(8.19)
Ineff. Indicator	γ	1.0000	0.1757	1.0000	0.9990	0.8965	0.9844
		(37772.93)	(0.62)	(5.95)	(154.31)	(2.35)	(8.08)
Log Likelihood		67.0817	59.2273	67.7642	60.8432	61.2605	62.7545
LR Test Statistics ($H_0 : \delta' = 0$)		18.0459	2.3371	19.4108	5.5689	6.4035	9.3914

Note : 1) The estimators were obtained by using Coelli's computer program (Frontier Version 4.1).
2) All models were regressed on data sets of 12 OECD countries over 1980, 1985, 1990, 1995 and 1998.
3) The numbers in parenthesis indicate t-values.

the 1 % critical level (Model 1 - Model 3 and Model 5), at 5 % level (Model 6) and at 10 % level (Model 4). These empirics support the prediction that there exist benefits from technology improvement in the production function over time, with Hicks-neutral efficiency growing at from 1 to 1.4 percent per year.

5.6.8 Basic Metals and Fabricated Metal Products

Table 5.8 shows that the null hypothesis that the parameters of the inefficiency jointly equal 0 can be rejected only for Model 3 at the 5 % critical level for industry ISIC 37 – Basic Metals and Fabricated Metal Products. At the 10 % level it is also rejected in Model 5. Both models tell the same story. Reductions in perceived corruption and time, holding corruption constant, are associated with reduced inefficiency. The institutional variables in the other models are not statistically significant. The time effects in the production function are positive and statistically significant at the 1 % critical level (Model 2 - Model 5 and 10 % level Model 6). These empirics suggest that the efficiency benefits from technology improvement in the production function grow at from 1.5 to 2.3 percent per year except Model 1, which has a much smaller point estimate and an insignificant coefficient.

5.6.9 Machinery and Equipment

Table 5.9 shows that in industry ISIC 38 – Machinery and Equipment rejects the null hypothesis that the coefficients of the inefficiency model jointly equal zero at the 5 percent critical level for only one model, Model 4.

Table 5.8: MLE of the Production Frontier and Determinants of Inefficiency
ISIC37: Basic Metals and Fabricated Metal Products

Variable	Parameter	M:1	M:2	M:3	M:4	M:5	M:6
Production:							
Constant	β_0	6.0243	4.1329	8.7919	10.5756	5.6526	4.1314
		(21.33)	(4.21)	(2.44)	(2.13)	(2.95)	(4.20)
ln(L)	β_1	3.8140	4.2149	1.4531	1.3237	2.0356	4.2117
		(4.10)	(4.87)	(0.90)	(0.96)	(1.66)	(4.83)
ln(K)	β_2	-1.4030	-1.3920	-0.7214	-1.4086	-0.3737	-1.4116
		(-3.00)	(-2.76)	(-1.27)	(-1.66)	(-0.71)	(-2.65)
$0.5[\ln(L)]^2$	β_3	-0.4603	-0.6360	-0.1880	-0.1840	-0.2551	-0.6361
		(-1.83)	(-3.27)	(-0.61)	(-0.73)	(-0.96)	(-0.79)
$0.5[\ln(K)]^2$	β_4	0.2028	0.1737	0.0695	0.1431	0.0469	0.1765
		(3.21)	(3.26)	(0.93)	(1.64)	(0.64)	(0.68)
ln(L)· ln(K)	β_5	-0.0848	-0.0260	0.0164	0.0459	-0.0075	-0.0248
		(-0.97)	(-0.26)	(0.19)	(0.48)	(-0.09)	(-0.06)
Time	τ_1	0.0352	0.1106	0.0968	0.0897	0.0974	0.1173
		(1.44)	(3.12)	(6.13)	(5.47)	(6.11)	(1.94)
Country Dummy		yes	yes	yes	yes	yes	yes
Inefficiencies:							
Constant	δ_0	0.5935	0.2368	1.3824	0.5254	0.9565	0.0201
		(2.60)	(1.38)	(3.45)	(0.47)	(1.93)	(0.02)
E. Freedom	δ_1	-0.1968			-0.2793	0.0401	0.0524
		(-0.45)			(-1.07)	(0.59)	(0.18)
Openness	δ_2		-0.0351		0.2014		-0.0253
			(-0.76)		(1.21)		(-0.11)
Corruption	δ_3			-0.1918		-0.1564	-0.0292
				(-3.19)		(-2.70)	(-0.31)
Time	τ_2	-0.0775	0.0154	-0.1797	-0.4156	-0.1494	-0.0003
		(-2.91)	(0.40)	(-3.39)	(-1.08)	(-2.81)	(0.00)
Variance	$\hat{\sigma}^2$	0.0141	0.0105	0.0317	0.0825	0.0200	0.0107
		(6.61)	(4.88)	(2.20)	(1.09)	(3.54)	(1.51)
Ineff. Indicator	γ	1.0000	0.0055	0.7717	0.9237	0.6073	0.0177
		(13.94)	(0.15)	(5.47)	(11.31)	(3.05)	(0.02)
Log Likelihood		52.5991	51.3549	54.9969	52.2632	54.4709	50.9596
LR Test Statistics ($H_0: \delta' = 0$)		3.7779	1.2895	8.5734	3.1060	7.5214	0.4988

Note : 1) The estimators were obtained by using Coelli's computer program (Frontier Version 4.1).
2) All models were regressed on data sets of 12 OECD countries over 1980, 1985, 1990, 1995 and 1998.
3) The numbers in parenthesis indicate t-values.

Economic freedom in this model has a positive coefficient with a relatively small standard error. The coefficients of time and openness are both insignificant. The null hypothesis is rejected at the 10 percent critical value for Models 1, 3, and 5, but the only individually significant coefficient is for economic freedom in Model 1, where it is significantly negative at a 5 percent critical value. The inefficiency indicator, γ, is significant—indicating inefficiency—in Model 1 and Models 3-5, but the inefficiency models do not do as good a job in explaining inefficiency as in the previous industries.

In general, the empirical results in this industry show that there are only loosely or no relationships between institutional factors and the inefficiency of the industry. The coefficient of economic freedom goes with the theory prediction only in Model 1, since the coefficients in all other models are all positive. Market openness and corruption have significant negative coefficients (critical level 5 %) in Model 6, but the inefficiency model is questionable because the null hypothesis of zero coefficients jointly for its parameters can only be rejected at a 25 percent critical value. This industry has more Hicksian-efficiency growth than any other industry. It is growing at an annual rate of between 2.8 and 3.6 percent per year with the coefficients significant in all models except Model 2 (with the smallest coefficient).

5.6.10 Transport Equipment

Table 5.10 represents the effects of the inefficiency models for industry ISIC 384-Transport Equipment. The joint null hypothesis of zero coefficients for all of the parameters of the inefficiency model cannot be rejected. The inefficiency indicator, γ, is only significant in one model, Model 2.

Table 5.9: MLE of the Production Frontier and Determinants of Inefficiency ISIC38: Machinery and Equipment

Variable	Parameter	M:1	M:2	M:3	M:4	M:5	M:6
Production:							
Constant	β_0	11.1090	10.5387	10.8456	11.9364	11.0162	11.5692
		(11.17)	(10.70)	(10.68)	(12.32)	(11.54)	(10.96)
ln(L)	β_1	0.1021	-0.1794	0.2516	0.3682	0.4590	0.0726
		(0.16)	(-0.20)	(0.37)	(0.67)	(0.78)	(0.06)
ln(K)	β_2	-0.9488	-0.6093	-0.9148	-1.2872	-1.0351	-0.7031
		(-2.40)	(-1.09)	(-2.36)	(-4.74)	(-3.25)	(-0.93)
$0.5[\ln(L)]^2$	β_3	-0.1755	-0.0106	-0.1461	-0.0427	-0.2735	-0.0725
		(-0.98)	(-0.01)	(-0.50)	(-0.26)	(-1.45)	(-0.27)
$0.5[\ln(K)]^2$	β_4	-0.0012	0.0041	-0.0043	0.0850	-0.0043	0.0045
		(-0.02)	(0.02)	(-0.05)	(2.06)	(-0.10)	(0.05)
$\ln(L)\cdot\ln(K)$	β_5	0.1969	0.1251	0.1760	0.1003	0.2114	0.1209
		(2.51)	(0.29)	(1.28)	(1.57)	(3.04)	(1.45)
Time	τ_1	0.1786	0.1394	0.1547	0.1764	0.1700	0.1531
		(9.95)	(0.69)	(6.63)	(24.59)	(13.00)	(5.67)
Country Dummy		yes	yes	yes	yes	yes	yes
Inefficiencies:							
Constant	δ_0	-0.9413	0.1762	0.4327	-1.2179	-0.5072	0.7162
		(-2.00)	(0.17)	(1.44)	(-3.04)	(-1.03)	(0.93)
E. Freedom	δ_1	-0.1968			0.1701	0.0860	0.1153
		(2.08)			(2.50)	(1.19)	(1.42)
Openness	δ_2		-0.0087		-0.0033		-0.1178
			(-0.03)		(-0.05)		(-1.78)
Corruption	δ_3			-0.0276		-0.0143	-0.0818
				(-0.99)		(-0.47)	(-2.14)
Time	τ_2	0.0234	-0.0102	-0.0252	0.0028	0.0150	-0.0324
		(0.67)	(-0.01)	(-0.52)	(0.09)	(0.35)	(-0.76)
Variance	$\hat{\sigma}^2$	0.0200	0.0237	0.0254	0.0355	0.0295	0.0124
		(10.85)	(0.76)	(5.62)	(6.28)	(6.22)	(1.36)
Ineff. Indicator	γ	1.0000	0.7837	1.0000	1.0000	0.9999	0.0841
		(1682.09)	(0.6829)	(535470.0)	(5758.75)	(908.11)	(0.14)
Log Likelihood		45.4964	43.0376	45.9422	49.6754	47.0924	45.6545
LR Test Statistics ($H_0 : \delta' = 0$)		5.8062	0.8884	6.6977	14.1642	8.9981	6.1223

Note : 1) The estimators were obtained by using Coelli's computer program (Frontier Version 4.1).
2) All models were regressed on data sets of 12 OECD countries over 1980, 1985, 1990, 1995 and 1998.
3) The numbers in parenthesis indicate t-values.

Table 5.10: MLE of the Production Frontier and Determinants of Inefficiency ISIC384: Transport Equipment

Variable	Parameter	M:1	M:2	M:3	M:4	M:5	M:6
Production:							
Constant	β_0	2.2892	2.4912	2.2886	2.2961	2.2869	2.2886
		(2.34)	(1.84)	(2.33)	(2.35)	(2.34)	(2.33)
ln(L)	β_1	5.2471	4.8051	5.2452	5.2425	5.2445	5.2421
		(6.14)	(6.14)	(6.00)	(6.22)	(6.06)	(6.18)
ln(K)	β_2	-1.2712	-1.0475	-1.2709	-1.2714	-1.2743	-1.2788
		(-2.62)	(-2.26)	(-2.42)	(-2.66)	(-2.50)	(-2.69)
$0.5[\ln(L)]^2$	β_3	-1.1111	-1.0052	-1.1050	-1.0991	-1.1131	-1.0927
		(-3.12)	(-3.99)	(-1.28)	(-3.91)	(-1.72)	(-4.40)
$0.5[\ln(K)]^2$	β_4	0.1500	0.1339	0.1521	0.1528	0.1502	0.1554
		(1.38)	(3.07)	(0.61)	(2.32)	(0.85)	(23.79)
$\ln(L)\cdot\ln(K)$	β_5	0.0371	0.0244	0.0337	0.0317	0.0384	0.0291
		(0.23)	(0.36)	(0.08)	(0.40)	(0.13)	(0.93)
Time	τ_1	0.1229	0.1055	0.1219	0.1251	0.1233	0.1261
		(2.07)	(4.52)	(1.11)	(1.64)	(2.04)	(1.90)
Country Dummy		yes	yes	yes	yes	yes	yes
Inefficiencies:							
Constant	δ_0	0.1334	1.0856	0.0429	0.0776	-0.0179	0.0418
		(0.20)	(0.99)	(0.04)	(0.84)	(-0.03)	(0.05)
E. Freedom	δ_1	-0.1968			-0.0071	0.0205	0.0282
		(-0.19)			(-0.20)	(0.14)	(0.16)
Openness	δ_2		-0.1581		-0.0019		-0.0147
			(-0.97)		(-0.09)		(-0.13)
Corruption	δ_3			-0.0056		-0.0160	-0.0181
				(-0.05)		(-0.12)	(-0.40)
Time	τ_2	-0.0141	-0.1521	-0.0099	-0.0075	-0.0162	-0.0182
		(-0.32)	(-0.55)	(-0.06)	(-0.20)	(-0.22)	(-0.13)
Variance	$\hat{\sigma}^2$	0.0146	0.0396	0.0148	0.0145	0.0147	0.0149
		(5.21)	(0.99)	(2.04)	(5.20)	(5.32)	(4.64)
Ineff. Indicator	γ	0.0038	0.6996	0.0116	0.0013	0.0068	0.0168
		(0.22)	(1.96)	(0.01)	(0.05)	(0.10)	(0.16)
Log Likelihood		42.0434	42.1875	41.8880	41.9461	42.0155	42.0773
LR Test Statistics ($H_0 : \delta' = 0$)		0.3630	0.6510	0.0521	0.1684	0.3071	0.4308

Note : 1) The estimators were obtained by using Coelli's computer program (Frontier Version 4.1).
2) All models were regressed on data sets of 12 OECD countries over 1980, 1985, 1990, 1995 and 1998.
3) The numbers in parenthesis indicate t-values.

No significant coefficients exist in the inefficiency model for this industry. Like its parent industry, ISIC 38, this industry experiences rapid growth of Hicks-neutral efficiency, with the significant growth rates ranging from 2.1 to 2.5 percent per year.

5.7 Output Elasticities

To consider the reliability of the production function, it is useful to examine the output elasticities of the inputs. The output elasticities are expressed as following from the production function, equation (5.5):

$$\Im_l = \frac{\partial \ln Y}{\partial \ln L} = \beta_1 + \beta_3 l_{it} + \beta_5 k_{it} \qquad (5.16)$$

and

$$\Im_k = \frac{\partial \ln Y}{\partial \ln K} = \beta_2 + \beta_4 k_{it} + \beta_5 l_{it} \qquad (5.17)$$

where, $\Im_l$ and $\Im_k$ represent the output elasticity of labor and capital, l_{it} is the natural log of labor input for country i and k_{it} the natural log of the capital stock. The output elasticities, which are based on the estimated production functions in this section, are presented in Table 5.11. The reported elasticities represent the average production elasticity of a country under Model 6 by ISIC 2-digit industry (including the manufacturing sector as a whole and ISIC 384 – Transport Equipment) over 5-time periods, 1980, 1985, 1990, 1995, and 1998.

As Table 5.11 shows, output elasticities, labor ($\Im_l$) and capital ($\Im_k$) vary by country and industry. $\Im_l$ in the manufacturing sector ranges from –0.3120 (U.S.A) to 1.0294 (Canada), while $\Im_k$ in the same sector records 0.3589 (Canada) to 0.5612 (U.S.A),

Table 5.11: Average Output Elasticities of the Frontier Production Function by Industry and Country

Country		ISIC 3	ISIC 31	ISIC 32	ISIC 33	ISIC 34	ISIC 35	ISIC 36	ISIC 37	ISIC 38	ISIC 384
Austria	$\Im_l$	0.0769	-0.1897	0.6510	0.6148	1.2887	0.0615	0.4022	0.6271	0.6556	1.0230
	$\Im_k$	0.4586	0.6331	0.2468	0.6385	0.1618	0.3210	0.2020	-0.0899	0.0181	-0.0465
Belgium	$\Im_l$	0.1944	-0.0617	0.6963	0.7021	1.2907	-0.0697	0.3759	0.6092	0.7075	0.2863
	$\Im_k$	0.4494	0.5815	0.2199	0.7209	0.1759	0.4594	0.2162	-0.0321	-0.0313	0.0497
Canada	$\Im_l$	1.0294	1.1752	1.0150	0.7674	1.4977	1.2064	0.1522	1.4121	0.8048	1.2915
	$\Im_k$	0.3589	0.4198	0.0719	0.4305	-0.1978	0.1765	0.4605	0.1122	-0.2026	0.2270
Finland	$\Im_l$	0.3822	0.4110	0.7392	0.6332	1.2410	0.4142	0.4071	1.1685	0.6508	1.1648
	$\Im_k$	0.4199	0.5867	0.2125	0.6577	-0.0234	0.1874	0.2883	-0.1709	-0.0325	-0.1167
France	$\Im_l$	0.5779	0.4603	0.9685	-	1.4408	0.6968	0.1244	0.9092	0.9359	0.6750
	$\Im_k$	0.4297	0.3571	0.0796	-	-0.1922	0.4538	0.3268	0.2529	-0.0454	0.3938
U.K	$\Im_l$	0.4072	0.4082	0.8705	0.7654	1.3365	0.5315	0.1599	0.7874	0.8753	0.4077
	$\Im_k$	0.4460	0.4152	0.1293	0.5903	-0.1403	0.4997	0.3182	0.1586	0.0051	0.3495
Italy	$\Im_l$	0.4069	0.5930	0.8601	0.7350	1.4560	0.7725	0.0906	0.7156	0.9584	0.8669
	$\Im_k$	0.4546	0.3697	0.1190	0.2623	-0.1394	0.4515	0.2930	0.3115	-0.0080	0.3567
Korea	$\Im_l$	0.4331	0.7419	0.7683	0.7813	1.4606	0.6615	0.1490	1.0859	0.9030	0.7479
	$\Im_k$	0.4419	0.4314	0.1677	0.6389	-0.0056	0.4080	0.3126	0.1968	-0.0086	0.3263
Netherlands	$\Im_l$	-0.0478	-0.5182	0.7218	0.6347	1.0988	-0.1754	0.4068	0.4814	0.6948	0.1447
	$\Im_k$	0.4830	0.5969	0.2175	0.9382	0.1183	0.5927	0.1976	-0.1022	0.0582	0.0997
Norway	$\Im_l$	0.6400	0.3716	0.8761	0.6675	1.2960	0.6674	0.4276	1.3447	0.5992	0.6962
	$\Im_k$	0.3775	0.6074	0.1591	0.7981	0.2460	0.0652	0.3354	-0.2045	-0.1256	-0.1272
Sweden	$\Im_l$	0.2866	0.3711	0.9194	0.6522	1.2230	0.2479	0.3963	0.7295	0.7073	0.1497
	$\Im_k$	0.4388	0.5772	0.1274	0.5702	-0.0293	0.2991	0.2825	-0.0478	0.0142	0.1587
U.S.A	$\Im_l$	-0.3120	-0.4463	0.7234	0.6247	1.0689	-0.0850	0.1441	-0.0024	1.0162	-0.9818
	$\Im_k$	0.5612	0.3968	0.1847	0.1535	-0.4538	0.9223	0.2051	0.4168	0.1874	0.6316

Note: 1) Production elasticities are obtained by following equations under Model 6 in Chapter 5.
2) Elasticities by country are calculated by averaging the elasticities of 1980, 1985, 1990, 1995, and 1998.

respectively. Even though U.S.A labor elasticity appears unreasonable, $\Im_l$ looks reliable in many countries such as U.K (0.4072), Finland (0.4069), France (0.5779) and Norway (0.6400). Note that capital elasticities, $\Im_k$'s in the manufacturing sector as a whole are very even across 12 OECD countries. Only U.S.A, Norway (0.3775) and Canada are out of the bound between 0.4001 and 0.4999.

The elasticities show big fluctuations by industry. The differences of elasticities between manufacturing industries within a country reflect imply which input factor should be employed for an additional production. However, it should be also noted that the elasticities out of a reasonable bound (too big or too small) can be caused by poor estimation performance, as shown ISIC 384 industry.

5.8 Conclusion

The dissertation investigated the effects of institutional factors on the technical inefficiencies of the manufacturing sector as a whole and of ISIC 2-digit (or 3-digit) industries under the manufacturing sector. Using 12 OECD country-samples, which were derived the OECD STAN 2002 data set, the dissertation expanded the study of Adkins, Moomaw and Savvides (2002) and confirmed that a country's institutions might cause TFP differences of the manufacturing industries in terms of inefficiency across countries. The dissertation identified the influence of institutions on technical inefficiency of the specific industries by estimating the extent to which institutional factors contribute to technical inefficiencies, which were defined as deviations from a stochastic frontier, rather than how institutional factors influence output growth or TFP growth.

The first finding of the dissertation is that economic freedom is a highly significant determinant of inefficiency in the manufacturing sector as whole and in many of the eight 2-digit manufacturing industries. The new finding confirms that the statement, "Institutions, in particular institutions that promote economic freedom, affect economic performance (Adkins, Moomaw and Savvides (2002) " is valid even under the manufacturing branches. This result implies that removing barriers to economic freedom contribute to economic performance by industry. The second empirical finding is that market size (openness) is also important determinant of the inefficiency for the overall manufacturing sector and in some 2-digit industries. The finding confirms the statement that "More open countries will tend to have faster productivity growth than more protectionist countries (Edwards, 1998)". The third is the effects of corruption on economic performance, which Jones (1997) argued with the diversion effects of institutional infrastructure. The empirical results document that corruption takes a negative effect on the technical efficiency of the overall manufacturing sector and many of the eight 2-digit industries. The finding on time effects on inefficiency varies by industry and model.

In conclusion, although empirical results of industry (ISIC384) are not statistically significant, the overall interpretations of the empirics in the dissertation indicate that countries with higher degrees of economic freedom and greater degrees of market openness and less degree of corruption tend to lie closer to the production frontier by industry.

Chapter VI.

SUMMARY AND CONCLUSION

6.1 Summary

The dissertation investigates total factor productivity (TFP) of manufacturing industries across 12 OECD countries in terms of the multilateral Malmquist index. There are systematic differences across countries in industry outputs that cannot be explained by differences in factor endowments. The assumption of identical production technology may not be appropriate at the sector or industry level of the economy.

The difference of industry productivity provides insights into comparative advantage in international trade. Productivity comparisons in the manufacturing sector are important for explaining economic growth as a whole, because manufacturing generates much new technology and has important spillover effects onto other sectors of the economy.

TFP has been actively studied to explain sectoral productivity differences across countries and over time because it is one of most comprehensive ways of comparing relative industry productivity. However, TFP studies still do not agree on "what are the real factors producing a high level of TFP". This is because TFP is measured as a residual, rather than being directly measured.

TFP measures the overall performance of the economy. Many factors make the TFP level different over time or across countries and regions. The TFP growth is the growth rate of output not explained by the growth in inputs, expressed by the growth rate of the Hicksian efficiency parameter.

Furthermore, productivity comparisons across countries require a different framework due to productivity convergence. To this end, the dissertation employs the CCD TFP index which is a consistent multilateral index for comparing relative productivity levels across economic entities. The CCD TFP index provides a basic framework for multilateral comparisons with a transitivity property. The transitivity property is necessary for comparing more than two entities simultaneously.

Using the CCD TFP index, the dissertation derives yearly TFP indices for 12 OECD countries, beginning in 1980 and presents multilateral productivity comparisons for specific manufacturing branches and the manufacturing sector as a whole. Specific manufacturing branches are identified by the 2-digit or 3-digit ISIC industry under the manufacturing sector.

TFP differences across countries are explained with a leader-follower framework in which one country is at the productivity frontier and follower countries are in a catch-up process. The dissertation investigates convergence in TFP for manufacturing industries in 12 OECD countries, using newly available data (OECD STAN 2002). The dissertation provides new findings of cross-country productivity convergence in the manufacturing sector. It also finds that a country's economic institutional factors are associated with both the level and growth of TFP at the level of the manufacturing sector.

TFP growth is an important contributor to economic growth over time and varies over space, with large cities having higher levels of TFP. In both the growth context and the spatial context, TFP level and growth is somehow related to the growth and diffusion of new knowledge or ideas. The dissertation investigates the effects of economic freedom, and EU membership on the relative productivity level.

The dissertation confirms that the country's institutions might cause TFP differences of manufacturing industries in terms of inefficiency across countries. In particular, the dissertation provides statistical evidence on whether or not improved economic performance is associated with increases in economic freedom and market openness, and decrease in corruption.

6.2 Conclusion

The dissertation presents several new findings by deriving the CCD multilateral TFP index for manufacturing industries across 12 OECD countries and by identifying the influence of institutions on technical inefficiency of the economy.

The first finding is that there were large productivity differences in sector or industry levels of the economy across countries. The United States was the highest productivity country during the 1980s and the 1990s in most industries among the compared countries. This finding confirms that there were substantial technology differences in the manufacturing sector as a whole and in 2-digit ISIC manufacturing branches among 12 OECD countries.

The second is that these TFP differences decreased over time from the 1980s to the 1990s. The gaps of the industry productivity fluctuated yearly, but in the long run diminished in a very stable manner. The existence of strong empirical evidence in support of β- convergence and σ -convergence support the idea that technology transfer occurs over time and across countries.

The third is that economic freedom has a positive effect on productivity levels of manufacturing industries. This finding confirms that greater economic freedom leads to greater productivity even in manufacturing industries. In addition, the finding confirms that TFP growth of the manufacturing sector is also positively related to economic freedom, suggesting that β–convergence is occurring.

The fourth is concerning the spatial context of productivity levels and economic freedom. The relationship between economic freedom and productivity is systematically different for EU and non-EU countries in the OECD. The effects of changes in economic freedom on productivity level are different over space. For the EU countries, TFP increases less rapidly with economic freedom than it does for non-EU countries.

The fifth is that technology transfer or R&D activity takes an important role in determining TFP growth on a specific industry level for a country behind the technological frontier. TFP growth in the frontier country induces faster TFP growth than the following countries by shifting out the production possibility set. Furthermore, the speed of diffusion of technology is determined by the TFP level of any country relative to that of the frontier country.

The sixth is concerning the effects of institutional factors on the technical inefficiencies of the manufacturing sector as a whole and of ISIC 2-digit (or 3-digit) industries under the manufacturing sector. The empirical finding is that the country's institutional factors make TFP levels different even under the manufacturing industries in terms of inefficiency across countries.

Economic freedom is a key determinant of the inefficiency of the manufacturing sector as a whole and manufacturing industries. The new finding confirms that the statement, "institutions affect economic performance (Adkins, Moomaw and Savvides, 2002) " is valid even under the manufacturing branches. Market size as measured by economy openness is also an important determinant of the inefficiency for the overall manufacturing sector and its sub-industries. At the same time, the finding confirms that "more open countries will tend to have faster productivity growth than more protectionist countries (Edwards, 1998)". The dissertation documents that corruption produces negative effects on the technical efficiencies of the overall manufacturing sector, eight 2-digit industries and one 3-digit industry. The negative effect of corruption on economic performance is equal to the diversion effect of institutional infrastructure (Jones, 1997). In brief, countries with higher degrees of economic freedom, greater degrees of market openness, and lesser degrees of corruption tend to lie closer to the production frontier in the manufacturing industries.

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APPENDIX

Appendix A: Data Description and Sources

1. OECD STAN (Structural Analysis) Database

The data on inputs and outputs used for calculating TFPs in this dissertation come from a number of sources. The main data source is the 2002 OECD STAN (Structural Analysis) Database, which provides information at the two- or three-digit industry level under ISIC (International Standard Industry Classification) on value added, labor input, gross fixed capital formulation and labor compensation. The dissertation uses data series for the selected manufacturing branches, which are divided into eight two-digit industries (ISIC 31-38), ISIC 384 and manufacturing sector (ISIC 3) as a whole. The countries analyzed consist of twelve countries, which have no data problems in all the variables over the period 1970-1998. They are Austria, Belgium, Canada, Finland, France, United Kingdom, Italy, Netherlands, Norway, Korea, Sweden and the United States.

2. Conversion Factors for Value added and Labor Compensation

The dissertation uses the OECD Industry-Specific Purchasing Power Parities (PPPs) for converting the domestic currencies of concerned countries into the US dollar values. The OECD PPPs comes from the OECD Purchasing Power Parities and Real Expenditures, which have been provided on a regular basis by the International Comparisons Project (ICP) mainly to compare income per head of a country.

3. Conversion Factors for Capital Stock Formulation

The conversion factor for capital stocks is different from the conversion factors for value added and labor compensation, since there are big gaps between the price index (conversion factor) from the production viewpoints and that from the final consumption viewpoints (Bart Ark, 1996). Therefore, it is reasonable to use the conversion factor (producer price) for converting the capital stocks value. This conversion factor comes from the overall investment prices of Summers and Heston (PWT 6).

4. Adjusting Labor Inputs

The labor input from the OECD STAN is numbers employed in a specific industry-country. For adjusting labor inputs by average working hours and labor skill, the dissertation uses the ILO database LABORSTA for average working hours by manufacturing industry and applies the OECD occupation/ skill breakdown with the BLS (Bureau of Labor Statistics) database.

5. R&D Expenditure

The R&D expenditure data come from OECD Research and Development expenditure in Industry 1977-1998. The data set presents R&D expenditure data (ANBERD: Analytical Business Enterprise Research and Development database) for 16 countries, as well as a zone total for the European Union. The ANBERD was designed to provide analysts with a comprehensive and internationally comparable data set on industrial R&D expenditure.

6. Economic Freedom

The index of economic freedom is from Economic Freedom of the World (EFW) of the Fraser Institute (www.freetheworld.com). The data set provides a measure of cross-country differences in economic freedom, using third-party data to help ensure objectivity. The EFW is composite index consisting of five areas such as: Size of Government, Expenditures, Taxes, and Enterprises; Legal Structure and Security of Property Rights; Access to Sound Money; Freedom to Exchange with Foreigners; Regulation of Credit, Labor, and Business.

Within those 5 major areas, 21 components are incorporated into the index. Counting the various sub-components, the EFW index utilizes 37 distinct pieces of data. Each component and sub-component is placed on a scale from 0 to 10 that reflects the distribution of the underlying data. The component ratings within each area are averaged to derive ratings for each of the 5 areas. The EFW index is the average of the five area ratings. (For discussion in depth, see Chapter 1 of *Economic Freedom of the World: 2002 Annual Report.*)

7. Market Openness

The market openness data also come from the Trade Openness Index (TOI) of the Fraser Institutes. The TOI is designed to measure the degree to which policies interfere with international exchange. The TOI has four general components: (a) tariff rates, (b) the black market exchange rate premium, (c) restrictions on capital movements, and (d) the actual size of the trade sector compared to the expected size. The ratings for each of these four components were averaged and used to derive a Trade Openness Index (TOI) for various years during the period from 1980 to 1998. (For discussion in depth, see *chapter 3 of Economic Freedom of the World: 2001 Annual Report*).

8. Corruption Degree

Corruption data comes from the Corruption Perceptions Index (TI CPI) of Transparency International. The TI Corruption Perceptions Index (CPI) is a composite index, derived from 16 different polls and surveys from 8 independent institutions, which were surveying business people, the general public and country analysts. Index 10 equals an entirely clean country while index 0 equals a country where business transactions are entirely dominated by kickbacks, extortion etc. (For discussion in depth, see *Background paper to the Corruption Perceptions Index, each year at www.transparency.org*).

Appendix B: Deriving Time Series of PPPs and Raw Estimated Labor Shares

B.1 Deriving Time Series of PPPs

The dissertation derived TFP indices during 1980-1998. But ICP PPPs only provided PPP_{cjt} at following years: 1985 (Ward), 1987, 1992, 1995, 1999 and 2002. The time series of PPP_{cjt} during 1980-1998 were obtained by extrapolating PPPs of each year as followings:

$$R_{cjt,t+p} = (\log ppp_{cjt+p} - \log ppp_{cjt}) / p \tag{B.1}$$

where, $R_{cjt,t+p}$ is a rate of change in PPPs during year t - year $t+p$, and ppp_{cjt} indicates the country c's ppp at year t in the industry j. And ppp_{cjt+p} represents ppp at year $t+p$. For example, $R_{cj85,87} = (\log ppp_{cj85,87} - \log ppp_{cj85})/2$ for $t = 1985$ and $t+p = 1987$. Applying the annual change rate, $R_{cjt,t+p}$, PPPs were derived for $t+1$, $t+2$, and $t+3$, respectively, as followings.

$$\begin{aligned} ppp_{cjt+1} &= ppp_{cjt} \cdot (1 + R_{cjt,t+p}) \\ ppp_{cjt+2} &= ppp_{cjt+1} \cdot (1 + R_{cjt,t+p}) \\ ppp_{cjt+3} &= ppp_{cjt+2} \cdot (1 + R_{cjt,t+p}) \end{aligned} \tag{B.2}$$

For instance, $ppp_{cj1986} = ppp_{cj85} \cdot (1 + R_{cj85,87})$.

During 1980-1984, PPPs should be adjusted, since there were no PPPs data by industry before 1985.

$$PI_{ct-p} = ppp^{T}_{ct} / ppp^{T}_{ct-p} \tag{B.3}$$

where, PI_{ct-p} is an index of overall expenditure PPPs at year t in terms of PPPs at year, $t-p$. ppp_{ct}^{T} represents the country c's overall expenditure *ppp* at year t.

Therefore,

$$ppp_{cjt-p} = PI_{ct-p} \cdot ppp_{cjt} \tag{B.4}$$

For example, $ppp_{cj1984} = PI_{c84} \cdot ppp_{cj85}$ for $t = 1985$

B.2: Raw Values on Estimated Labor Shares by Manufacturing Branch

Model: $s_{ct} = \alpha + \beta \ln(k_{ct} / l_{ct}) + \varepsilon_{ct}$

	Coefficient	Austria	Belgium	Canada	Finland	France	U.K
ISIC 31	$\hat{\alpha}$	0.3194	0.5585	0.8316	0.4282	0.2455	0.6835
	$\hat{\beta}$	0.0521	0.0076	-0.0574	0.0324	0.0503	-0.0086
ISIC 32	$\hat{\alpha}$	0.6549	0.9359	0.9217	0.7110	1.1996	0.6662
	$\hat{\beta}$	0.0122	-0.0622	-0.0504	0.0055	-0.0997	0.0203
ISIC 33	$\hat{\alpha}$	0.2167	0.6722	0.8899	0.8653	-	0.5251
	$\hat{\beta}$	0.0664	-0.0187	-0.0248	-0.0317	-	0.0312
ISIC 34	$\hat{\alpha}$	0.7073	0.7052	0.7748	0.8101	0.6463	0.9295
	$\hat{\beta}$	-0.0074	-0.0119	-0.0181	-0.0368	0.0037	-0.0360
ISIC 35	$\hat{\alpha}$	0.4230	0.6445	0.9679	0.4159	0.0503	0.6985
	$\hat{\beta}$	0.0335	-0.0199	-0.0663	0.0105	0.0896	-0.0086
ISIC 36	$\hat{\alpha}$	0.4238	0.7624	0.5588	0.7516	1.2934	0.9345
	$\hat{\beta}$	0.0373	-0.0273	0.0175	-0.0271	-0.1083	-0.0447
ISIC 37	$\hat{\alpha}$	0.5925	0.6663	0.7110	0.6994	0.6826	0.7798
	$\hat{\beta}$	0.0278	0.0289	0.0068	-0.0112	0.0031	0.0037
ISIC 38	$\hat{\alpha}$	0.6293	0.9139	0.8717	0.8858	0.7092	0.8211
	$\hat{\beta}$	0.0167	-0.0496	-0.0429	-0.0475	-0.0002	-0.0271
ISIC 384	$\hat{\alpha}$	0.6427	0.9933	0.9259	0.7750	1.1188	1.1942
	$\hat{\beta}$	0.0222	-0.0821	-0.0477	0.0059	-0.0591	0.0709

B.2: Raw Values on Estimated Labor Shares by Manufacturing Branch (~Continued)

Model: $s_{ct} = \alpha + \beta \ln(k_{ct} / l_{ct}) + \varepsilon_{ct}$

	Coefficient	Italia	Korea	Netherlands	Norway	Sweden	U.S.A.
ISIC 31	$\hat{\alpha}$	0.5670	0.1875	0.6005	0.5079	1.4612	0.6508
	$\hat{\beta}$	-0.0199	0.0203	-0.0145	0.0710	-0.1323	-0.0265
ISIC 32	$\hat{\alpha}$	0.8751	0.2761	0.8018	0.7615	1.2605	0.9084
	$\hat{\beta}$	-0.0663	0.0709	-0.0357	0.0073	-0.0680	-0.0366
ISIC 33	$\hat{\alpha}$	0.7821	0.4037	0.6760	0.5738	0.6061	0.7588
	$\hat{\beta}$	-0.0645	0.0456	-0.0120	0.0589	0.0060	-0.0321
ISIC 34	$\hat{\alpha}$	0.9193	0.3933	0.6760	0.7302	0.7496	0.8183
	$\hat{\beta}$	-0.0665	0.0398	-0.0120	0.0007	-0.0123	-0.0286
ISIC 35	$\hat{\alpha}$	1.0284	0.2334	0.4364	0.5571	0.7624	0.8646
	$\hat{\beta}$	-0.0820	0.0180	0.0079	0.0053	-0.0332	-0.0553
ISIC 36	$\hat{\alpha}$	0.6706	0.1887	0.6312	0.6252	1.4051	0.7372
	$\hat{\beta}$	-0.0228	0.0554	-0.0069	0.0032	-0.1188	0.0000
ISIC 37	$\hat{\alpha}$	0.5060	0.2115	0.7141	0.6444	0.7864	0.8558
	$\hat{\beta}$	0.0161	0.0340	0.0000	0.0085	-0.0136	-0.0263
ISIC 38	$\hat{\alpha}$	0.7363	0.2214	0.8716	0.7484	0.9800	0.8576
	$\hat{\beta}$	-0.0247	0.0573	-0.0228	0.0171	-0.0429	-0.0253
ISIC 384	$\hat{\alpha}$	0.5377	0.2982	0.6760	0.9266	0.8180	0.7519
	$\hat{\beta}$	0.0426	0.0294	-0.0120	-0.0176	-0.0282	0.0089

Appendix C: Stochastic Frontier Production Function

This appendix presents the estimator derivation procedures and the key results of the inefficiency stochastic frontier model, which were developed by Battese and Coelli (1993) and reproduced by Adkins, Moomaw and Savvides (2002). The stochastic frontier model is expressed by

$$y_{it} = x_{it} \cdot \beta + E_{it} \tag{C.1}$$

and

$$E_{it} = V_{it} - U_{it} \tag{C.2}$$

where $i = 1, 2, \ldots, N$, and $t = 1, 2, \ldots, T$. y_{it} represents value added (logarithm) of the ith country in the $t\,th$ time period. x_{it} indicates $1 \times k$ vector of input quantities of ith country. β is a vector of unknown parameters, which should be estimated in the model. V_{it}'s are random variables which are assumed to be iid N(0, σ_v^2) and independent of the U_{it}.

$$U_{it} = z_{it} \cdot \delta + W_{it} \tag{C.3}$$

The inefficiency, U_{it}, is represented for opposite reflection of the technical efficiency as following:

$$TE_{it} = \exp(-U_{it}) = \exp(-z_{it}\delta - W_{it}) \tag{C.4}$$

U_{it} represents non-negative random variables which are assumed to account for technical inefficiency in production, and independently distributed as truncation at zero of the N(m_{it}, σ_v^2) distribution.

$$m_{it} = z_{it} \cdot \delta \tag{C.5}$$

where, z_{it} is a $1 \times m$ vector of country-specific variables which may generate the inefficiency. δ represents $m \times 1$ vector of unknown parameters of the country-specific inefficiency variables.

The probability density functions (pdf) of v_{it} and u_{it} are

$$f_v(v) = \frac{\exp(-\frac{1}{2}v^2 / \sigma_v^2)}{\sqrt{2\pi}\sigma_v}, \qquad -\infty < v < \infty \tag{C.6}$$

and

$$f_U(u) = \frac{\exp(-\frac{1}{2}(u - z\delta)^2 / \sigma_U^2)}{\sqrt{2\pi}\sigma_U \Phi(z\delta / \sigma_U)}, \qquad u \geq 0 \tag{C.7}$$

where the subscripts, i and t are omitted for convenience in the presentation and the function $\Phi(\cdot)$ represents the distribution function for the standard normal random variable.

Let the overall error term of the liner model be denoted E and note that $V = E + U$. The joint density function for $E = V - U$ and U is

$$\begin{aligned} f_{E,U}(e,u) &= \frac{\exp\{-\frac{1}{2}[(e+u)^2 / \sigma_V^2] + [(u - z\delta)^2 / \sigma_U^2]\}}{2\pi\sigma_U\sigma_V\Phi(z\delta / \sigma_U)}, \qquad u \geq 0 \\ &= \frac{\exp\{-\frac{1}{2}[((u - u_*)^2 / \sigma_*^2] + (e^2 / \sigma_V^2) + (z\delta / \sigma_U)^2 - (u_* / \sigma_*)^2\}}{2\pi\sigma_U\sigma_V\Phi(z\delta / \sigma_U)} \end{aligned} \tag{C.8}$$

or, alternatively, using re-parameterization, $u_* = \frac{\sigma_V^2 z\delta - \sigma_U^2 e}{\sigma_V^2 + \sigma_U^2}$ and $\sigma_*^2 = \sigma_U^2\sigma_V^2 / (\sigma_V^2 + \sigma_U^2)$

yields

$$f_{E,U}(e,u) = \frac{\exp\{-\frac{1}{2}[(u-u_*)^2/\sigma_*^2] + [(e+z\delta)^2/(\sigma_V^2+\sigma_U^2)]\}}{2\pi\sigma_U\sigma_V\Phi(z\delta/\sigma_U)}, \quad u \geq 0 \tag{C.9}$$

The density function for $E = V - U$ is

$$f_E(e) = \frac{\exp[-\frac{1}{2}(e^2/\sigma_V^2) + (z\delta/\sigma)^2 - (u_*/\sigma_*)^2]}{\sqrt{2\pi}\sigma_U\sigma_V\Phi(z\delta/\sigma_U)} \int_0^\infty \frac{\exp[-\frac{1}{2}(u-u_*)^2/\sigma_*^2]}{\sqrt{2\pi}} du$$

$$= \frac{\exp\{-\frac{1}{2}[(e^2/\sigma_V^2) + (z\delta/\sigma)^2 - (u_*/\sigma_*)^2]\}}{\sqrt{2\pi}(\sigma_V^2+\sigma_U^2)^{1/2}[\Phi(z\delta/\sigma_U)/\Phi(u_*/\sigma_*)]}, \qquad u \geq 0$$

(C.10)

or, alternatively,

$$f_E(e) = \frac{\exp\{-\frac{1}{2}(e+z\delta)^2/(\sigma_V^2+\sigma_U^2)\}}{\sqrt{2\pi}(\sigma_V^2+\sigma_U^2)^{1/2}[\Phi(z\delta/\sigma_U)/\Phi(u_*/\sigma_*)]} \tag{C.11}$$

The conditional density function for U given $E = e$ is thus

$$f_{U|E=e}(u) = \frac{\exp-\frac{1}{2}[(u-u_*)^2/\sigma_*^2]}{\sqrt{2\pi}\sigma_*\phi(u_*/\sigma_*)}, \qquad u \geq 0 \tag{C.12}$$

The conditional expectation of e^{-U}, given $E = e$, is

$$E(e^{-U}|E=e) = \{\exp[-u_* + \frac{1}{2}\sigma_*^2]\}\{\Phi[(u_*/\sigma_*) - \sigma_*]/\Phi(u_*/\sigma_*)\} \tag{C.13}$$

The density function for production, Y_{it}, is expressed by using expression of the equation (C.11) as following:

$$f_{Y_{it}}(y_{it}) = \frac{\exp-\frac{1}{2}\{\frac{(y_{it}-x_{it}\beta+z_{it}\delta)^2}{\sigma_V^2+\sigma_U^2}\}}{\sqrt{2\pi}(\sigma_V^2+\sigma_U^2)^{1/2}[\phi(d_{it})/\phi(d_{it}^*)]} \tag{C.14}$$

where, $d_{it} = z_{it}\delta/\sigma_U$, $d_{it}^* = u_{it}^*/\sigma_*$, *and* $u_{it}^* = [\sigma_V^2 z_{it}\delta - \sigma_U^2(y_{it}-x_{it}\beta)]/(\sigma_V^2+\sigma_U^2)$.

Let T_i be observations from the $i\,th$-entity, where $1 \le T_i \le T$ and $Y_i \equiv (Y_{i1}, Y_{i2}, \ldots, Y_{iT_i})'$ denotes the vector of the T_i production value in equation (B.1). Then the logarithm of the likelihood function for the sample observations, $y \equiv (y_1', y_2', \ldots, y_T')'$ is expressed by:

$$\begin{aligned} L^*(\theta^*; y) = &-\frac{1}{2}(\sum_{i=1}^{N} T_i)\{\ln 2\pi + \ln(\sigma_V^2 + \sigma_U^2) \\ &-\frac{1}{2}\sum_{i=i}^{N}\sum_{t=1}^{T}[(y_{it} - x_{it}\beta + z_{it}\delta)^2 / (\sigma_V^2 + \sigma_U^2) \\ &-\sum_{i=i}^{N}\sum_{t=1}^{T}[\ln\phi(d_{it}) - \ln\phi(d_{it}^*)] \end{aligned} \tag{C.15}$$

where, $\theta^* = (\beta', \delta', \sigma_V^2, \sigma_U^2)'$.

By defining $\sigma_S^2 \equiv \sigma_V^2 + \sigma_U^2$ and $\gamma \equiv \sigma_U^2 / \sigma_S^2$, the logarithm likelihood function is expressed by:

$$\begin{aligned} L^*(\theta\ ; y) = &-\frac{1}{2}(\sum_{i=1}^{N} T_i)\{\ln 2\pi + \ln\sigma_S^2\} \\ &-\frac{1}{2}\sum_{i=i}^{N}\sum_{t=1}^{T}[(y_{it} - x_{it}\beta + z_{it}\delta)^2 / \sigma_S^2] \\ &-\sum_{i=i}^{N}\sum_{t=1}^{T}[\ln\Phi(d_{it}) - \ln\Phi(d_{it}^*)] \end{aligned} \tag{C.16}$$

where, $d_{it} = z_{it}\delta / (\gamma\sigma_U^2)^{1/2}$, $d_{it}^* = u_{it}^* / [\gamma(1-\gamma)\sigma_S^2)^{1/2}$, $u_{it}^* = (1-\gamma)z_{it}\delta - \gamma(y_{it} - x_{it}\beta)$, $\sigma_* = [\gamma(1-\gamma)\sigma_S^2]^{1/2}$ and $\theta\ = (\beta', \delta', \sigma_S^2, \gamma)'$.

The first order condition (partial derivative) of the logarithm of the likelihood function with respect to the parameters, $\beta, \delta, \sigma_S^2$ and γ, are derived as following:

$$\frac{\partial L^*}{\partial \beta} = \sum_{i=i}^{N}\sum_{t=1}^{T}\{\frac{(y_{it} - x_{it}\beta + z_{it}\delta)}{\sigma_S^2} + \frac{\phi(d_{it}^*)}{\Phi(d_{it}^*)} \cdot \frac{\gamma}{\sigma_*}\}x_{it}' \tag{C.17}$$

where $\phi(\cdot)$ represents the probability density function for the standard normal random variable.

$$\frac{\partial L^*}{\partial \delta} = -\sum_{i=i}^{N}\sum_{t=1}^{T}\{\frac{(y_{it} - x_{it}\beta + z_{it}\delta)}{\sigma_S^2} + [\frac{\phi(d_{it})}{\Phi(d_{it})} \cdot \frac{1}{(\gamma\sigma_S^2)^{1/2}} - \frac{\phi(d_{it}^*)}{\Phi(d_{it}^*)} \cdot \frac{(1-\gamma)}{\sigma_*}]\}z_{it}' \tag{C.18}$$

$$\frac{\partial L^*}{\partial \sigma_S^2} = -\frac{1}{2}(\frac{1}{\sigma_S^2})\{(\sum_{t=1}^{T} T_i) - \sum_{i=i}^{N}\sum_{t=1}^{T}[\frac{\phi(d_{it})}{\Phi(d_{it})}d_{it} - \frac{\phi(d_{it}^*)}{\Phi(d_{it}^*)}d_{it}^*] - \sum_{i=i}^{N}\sum_{t=1}^{T}\frac{(y_{it} - x_{it}\beta + z_{it}\delta)}{\sigma_S^2}\} \tag{C.19}$$

$$\frac{\partial L^*}{\partial \gamma} = \sum_{i=i}^{N}\sum_{t=1}^{T}\{\frac{\phi(d_{it})}{\Phi(d_{it})}\frac{d_{it}}{2\gamma} + \frac{\phi(d_{it}^*)}{\Phi(d_{it}^*)}[\frac{(y_{it} - x_{it}\beta + z_{it}\delta)}{\sigma_*} + \frac{d_{it}^*(1-2\gamma)}{2\gamma(1-\gamma)\sigma_*^2}]\} \tag{C.20}$$

VITA 2

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