The Importance of ICT for the Knowledge Economy: A Total Factor Productivity Analysis for Selected OECD Countries

İsmail Seki
Ege University, Turkey

Abstract

Science, technology and innovation have become key factors contributing to economic growth in both advanced and developing economies. In the knowledge economy, information circulates at the international level through trade in goods and services, direct investment and technology flows, and the movement of people. Information and communication technologies (ICT) have been at the heart of economic changes for more than a decade. ICT sector plays an important role, notably by contributing to rapid technological progress and productivity growth. Firms use ICTs to organize transnational networks in response to international competition and the increasing need for strategic interaction. As a result, multinational firms are a primary vehicle of the everspreading process of globalization. New technologies and their implementation in productive activities are changing the economic structure and contributing to productivity increases in OECD economies.

Economic competitiveness depends on productivity level and in the knowledge economy, ICT sectors determine the productivity level. As a result , we can say that the power of economic competitiveness of a country depends on the productivity of its ICT sector.

There are two ways to improve the TFP of ICT and to improve the power of competitiveness. First of all, if the selected countries solve their inefficiency problem by reallocation of resources, they can improve their TFP of the ICT sector and as a result they can be more competitive. Secondly, the technological improvement in these countries creates an expectation about increasing TFP of ICT sector for future. If there will be a sustainable technological improvement by innovation, it will cause a sustainable increase in the TFP of ICT sector and as a result it will cause a sustainable increase in competitiveness.

Introduction

Advance economies are becoming knowledge based economies in an increasing scope in the context of generation, using and dissemination of knowledge because of the fast improvements in science and technology. As a result of this progress, the importance of knowledge as a production factor is increasing. The engine of economic growth and development is knowledge, not physical goods or natural resources in such an economics based on knowledge networks. Knowledge economics is a term that is used to define an economic system in which the knowledge is generated, disseminated and used by firms, institutions, individuals and society to reach an advance social and economic development.

There are two kinds of knowledge called tacit knowledge and codified knowledge. While these two knowledge are complementary, the generation processes and the roles on learning process of these knowledge are very different from each other.

Tacit knowledge is not included by machineries. It is a kind of knowledge that emerges as a result of interaction between the environment, structure of social institutions, attitudes and norms. This knowledge contains the expertise and knowledge that is obtained by the experience of the production, marketing and distribution process. Additionally, it contains attitude forms that is settled and developed through time. Tacit knowledge can not be transformed into universal codes easily because it is the product of the specific and complex environment. Because of that feature, tacit knowledge is not universally accessible like codified knowledge. Tacit knowledge is also divided into two sub-groups called internal and external tacit knowledge. Internal tacit knowledge is formed by the rules and skills (know-how) that arise as a result of learning by doing process. However the source of the external tacit knowledge is social life. Entrepreneurs systematically see each other by means of various clubs and associations, local cooperatives, councils of regional management means.

Codified knowledge is a kind of knowledge which is included in machineries or in general, included in production devices. Because of that character, codified knowledge has the facility that everyone can reach by using universal codes. This relation is defined as hardware/software relation. Software is the knowledge or language that explains the universal usage of the machinery while hardware is the knowledge which is included in machinery. We can divide the codified knowledge into two sub-group called internal and external codified knowledge. Internal codified knowledge is the result of research and development (R&D) activities. External codified knowledge emerges as a result of recombination of different information bits in different contents during the collective works (projects) of universities, R&D departments of firms and different research centers.

Because of the pressure of global competition, firms are both increasing the scope of using the technology, especially information and communication technologies (ICT), and try to adopt their organizational structures to the process of knowledge economics (Kelleci, 2003:4).

In the knowledge economy, the most important issue is to generation, using and dissemination of knowledge. That issue gives ICT sector a vital importance because ICT sector is the fastest way of using and disseminating knowledge. As a result, we can say that the power of economic competitiveness of a country depends on the productivity of its ICT sector.

There is literature review in the second part of the study. In the third part, methodology that is used is explained. In the forth part, the data and the source of data is examined. In the fifth part, there is the empirical analysis of selected OECD countries. In the sixth and the last part, there is conclusion about the empirical analysis.

Literature Review

There are several studies about Total Factor Productivity (TFP) in the literature. When we look at the literature, we can see that most of the studies in literature try to explain the relationship between TFP and economic growth. Here we mention the some selected empirical studies in the literature.

Hulten (2000) argues that economists have long recognized that total factor productivity is an important factor in the process of economic growth. However, just how important it is has been a matter of ongoing controversy. Part of this controversy is about methods and assumptions. Total factor productivity growth is estimated as a residual, using index number techniques. It is thus a measure of our ignorance,' with ample scope for measurement error. Another source of controversy arises from sins of omission, rather than commission. A New Economy critique of productivity points to unmeasured gains in product quality, while an environmental critique points to the unmeasured costs of growth. This essay is offered as an attempt to address these issues. Its first objective is to explain the origins of the growth accounting and productivity methods now under scrutiny. It is a biography of an idea, is intended to show what results can be expected from the productivity framework and what cannot. The ultimate objective is to demonstrate the considerable utility of the idea, as a counter-weight to the criticism, often erroneous, to which it has been subjected. Despite its flaws, the residual has provided a simple and internally consistent intellectual framework for organizing data on economic growth, and has provided the theory to guide a considerable body of economic measurement.

Miller and Upadhyay (2002) try to find the answer of that question; "Do openness and human capital accumulation promote economic growth?" While intuition argues yes, the existing empirical evidence provides mixed support for such assertions. They examine Cobb-Douglas production function specifications for a 30-year panel of 83 countries representing all regions of the world and all income groups. They estimate and compare labor and capital elasticities of output per worker across each of several income and geographic groups, finding significant differences in production technology. Then they estimate the total factor productivity series for each classification.

Using determinants of total factor productivity that include, among many others, human capital, openness, and distortion of domestic prices relative to world prices, they find significant differences in results between the overall sample and sub-samples of countries. In particular, a policy of outward orientation may or may not promote growth in specific country groups even if geared to reducing price distortion and increasing openness. Human capital plays a smaller role in enhancing growth through total factor productivity.

Scarpetta and Tressel (2004) present empirical evidence on the determinants of industry-level multifactor productivity growth. They focus on 'traditional factors,' including the process of technological catch up, human capital, and research and development (R&D), as well as institutional factors affecting labor adjustment costs. Their analysis is based on harmonized data for 17 manufacturing industries in 18 industrial economies over the past two decades. The disaggregated analysis reveals that the process of technological convergence takes place mainly in low-tech industries, while in high-tech industries, country leaders tend to pull ahead of the others. The link between R&D activity and productivity also depends on technological characteristics of the industries: while there is no evidence of R&D boosting productivity in low-tech industries, the effect is strong in high-tech industries, but the technology leaders tend to enjoy higher returns on R&D expenditure compared with followers. There is also evidence in the data that high labor adjustment costs (proxied by the strictness of employment protection legislation) can have a strong negative impact on productivity. In particular, when institutional settings do not allow wages or internal training to offset high hiring and firing costs, the latter reduce incentives for innovation and adoption of new technologies, and lead to lower productivity performance. Albeit drawn from the experience of industrial countries, this result may have relevant implications for many developing economies characterized by low relative wage flexibility and high labor adjustment costs. This paper--a joint product of the Social Protection Team, Human Development Network, World Bank, and the International Monetary Fund is part of a larger effort to understand what drives productivity growth.

Hallward-Driemeier et. al. (2002) use new firm level data from five East Asian countries to explore the patterns of manufacturing productivity across the region. One of the striking patterns that emerges is how the extent of openness and the competitiveness of markets affects the relative productivity of firms across the region. Firms with foreign ownership and firms that export are significantly more productive, and the productivity gap is larger the less developed is the local market. They exploit the rich set of firm characteristics available in the database to explore the sources of export firms' greater productivity. They argue that it is in aiming for export markets that firms make decisions that raise productivity. It is not simply that more-productive firms self-select into exporting; rather, firms that explicitly target export markets consistently make different decisions regarding investment, training, technology and the selection of inputs, and thus raise their productivity.

Han et. al. (2003) compare the sources of growth in East Asia with the rest of the world, using a methodology that allows one to decompose total factor productivity (TFP) growth into technical efficiency changes (catching up) and technological progress. It applies a varying coefficients frontier production function model to aggregate data for the period 1970-1990, for a sample of 45 developed and developing countries. Their results are consistent with the view that East Asian economies were not outliers in terms of TFP growth. Of the high-performing East Asian economies, their methodology identifies South Korea as having the highest TFP growth, followed by Singapore, Taiwan and Japan. Their methodology also allows us to separately estimate technical efficiency change, which is a component of TFP growth, and they find that, in general, the estimated technical efficiency of the high-performing East Asian economies was not out of line with the rest of the world.

Felipe (1997) surveys the empirical literature on total factor productivity (TFP) and the sources of growth in the East Asian countries. It raises the question whether the literature has helped us understand better the factors that have propelled growth in the region. The paper discusses the main theoretical aspects in the estimation of TFP growth, as well as the empirical results, and provides a survey of estimates of TFP growth for nine East and Southeast Asian countries. It is concluded that:

(i) The main merit of the literature is that it has helped focus the attention of scholars on the growth process of East Asia, and has made countries in the region aware of the importance of productivity;

(ii) The theoretical problems underlying the notion of TFP are so significant that the whole concept should be discarded;

(iii) The TFP growth estimates are contentious: they vary significantly, even for the same country and time period, depending on assumptions and data sources;

(iv) Research on growth in East Asia based on the estimation of TFP growth is an activity subject to decreasing returns. If we are to advance in our understanding of how East Asia grew during the last 30 years we need new avenues of research.

OECD Growth Project edited by Dirk Pilat (2003) is an important project about productivity and growth. Growth and productivity are on the policy agenda in many OECD countries, and therefore also affect work of the OECD. The organization was asked in 1999 by its member countries to examine the variation in growth performance in the OECD area, analyze its causes and provide guidance for policy making. The strong performance of the United States at the time and related claims about a "new economy" were among the reasons for this demand, as was the poor performance of several other OECD countries at the time.

Ark (2002) try to examine productivity and income differentials among OECD countries. Using a conceptual framework, which is rooted in a traditional growth accounting framework — but with several extensions — he focused on two sources of growth differentials. First he looked at the role of the "new economy," in the sense that *ICT has been a source of faster productivity growth in the United States***.** Then he looked at the impact of the creation of intangible capital, which has been identified as a necessary condition for exploiting the productivity advantages of ICT investment. The analysis suggests that differential realization of the potential to generate productivity accelerations from ICT has contributed to the differential economic growth performance among OECD countries. At the same time, it is difficult to precisely measure the contribution of the various factors at the macroeconomic level. One may even argue that the traditional methods for analyzing and measuring the relation between inputs and output at the macroeconomic level are, increasingly, failing to describe the processes that drive changes and differences in growth performance between firms.

Guerrieri et. al. (2005) argue that in the last half of the 1990s, labor productivity growth rose in the U.S. and fell almost everywhere in Europe. They document changes in both capital deepening and multifactor productivity (MFP) growth in both the information and communication technology (ICT) and non-ICT sectors. They view MFP growth in the ICT sector as investment-specific productivity (ISP) growth. They perform simulations sug

gested by the data using a two-country DGE model with traded and nontraded goods. For ISP, they consider level increases and persistent growth rate increases that are symmetric across countries and allow for costs of adjusting capital-labor ratios that are higher in one country because of structural differences. ISP increases generate investment booms unless adjustment costs are too high. For MFP, they consider persistent growth rate shocks that are asymmetric. When such MFP shocks affect only traded goods (as often assumed), movements in 'international' variables are qualitatively similar to those in the data. However, when they also affect nontraded goods (as suggested by the data), movements in some of the variables are not. To obtain plausible results for the growth rate shocks, it is necessary to assume slow recognition.

Nicoletti and Scarpetta (2003) look at differences in the scope and depth of pro-competitive regulatory reforms and privatization policies as a possible source of cross-country dispersion in growth outcomes. They suggest that, despite extensive liberalization and privatization in the OECD area, the cross-country variation of regulatory settings has increased in recent years, lining up with the increasing dispersion in growth. The authors then investigate empirically the regulation-growth link using data that cover a large set of manufacturing and service industries in OECD countries over the past two decades and focusing on multifactor productivity (MFP), which plays a crucial role in GDP growth and accounts for a significant share of its cross-country variance. Regressing MFP on both economywide indicators of regulation and privatization and industry-level indicators of entry liberalization, the authors find evidence that reforms promoting private governance and competition (where these are viable) tend to boost productivity. In manufacturing, the gains to be expected from lower entry barriers are greater the further a given country is from the technology leader. So, regulation limiting entry may hinder the adoption of existing technologies, possibly by reducing competitive pressures, technology spillovers, or the entry of new high-technology firms. At the same time, both privatization and entry liberalization are estimated to have a positive impact on productivity in all sectors. These results offer an interpretation to the observed recent differences in growth patterns across OECD countries, in particular between large continental European economies and the United States. Strict product market regulations--and lack of regulatory reforms are likely to underlie the relatively poorer productivity performance of some European countries, especially in those industries where Europe has accumulated a technology gap (such as information and communication technology-related industries). These results also offer useful insights for non-OECD countries. In particular, they point to the potential benefits of regulatory reforms and privatization, especially in those countries with large technology gaps and strict regulatory settings that curb incentives to adopt new technologies. This paper--a product of the Social Protection Team, Human Development Network is part of a larger effort in the network to understand what drives productivity growth.

Bernard and Jones (1996) examine the role of sectors in aggregate convergence for fourteen OECD countries during 1970-87. The major finding is that manufacturing shows little evidence of either labor productivity or multifactor productivity convergence, while other sectors, especially services, are driving the aggregate convergence result. To determine the robustness of the convergence results, the paper introduces a new measure of multifactor productivity which avoids many problems inherent to traditional measures of total factor productivity when comparing productivity levels. The lack of convergence in manufacturing is robust to the method of calculating multifactor productivity.

Kask and Sieber (2002) argue that among manufacturing industries employing a substantial proportion of research and development and technology-oriented workers, the information technology industries exhibited particularly strong productivity growth over the 1987-99 period. This article examines productivity developments in a set of detailed industries representing the high-tech manufacturing sector and uses aggregate measures that were developed to permit comparison with the manufacturing industry as a whole. In addition to labor productivity and related measures, the analysis includes multifactor productivity. This analysis is based on data produced by the BLS Office of Productivity and Technology, and the industries used are classified at the three-digit SIC level.

When we look at the power of competitiveness in literature, we see that economists directly relate competitiveness power to TFP. According to Bryan (1994), the industry which has the highest productivity level relative to its competitors is the successful industry. According to Khemani (1997), competitive power is has the same meaning with productivity. Competitive power is the power of increasing TFP of firms/industries/countries.

Data

In this study we use Telecommunications data as a proxy of ICT sector because of the data restrictions about ICT sector. The reason of selected telecommunications data as a proxy is that telecommunication is an important part of the ICT sector and it has a vital role in dissemination of knowledge. Our data source is OECD Telecommunications Database 2005 which can be reached at that web address [http://oecd-stats.ingenta.com/OECD/TableViewer/dimView.aspx]. We use panel data between the period 1980-2003 for selected 26 OECD countries. Our dependent variable is GDP (in USD) and independent variables are Total Staff in Mobile Telecommunication and Gross Fixed Capital Formation. We had to omit the data related with Czech Republic, Hungary, Poland and Slovak Republic. Because there are no sustainable data for the period 1980-2003 for these countries.

Methodology

The Malmquist Productivity Index

The Malmquist productivity index (MPI), as proposed by Caves, Christensen and Diewert (1982), is defined using distance functions, which allow one to describe multi-input, multioutput production without involving explicit price data and behavioural assumptions. Distance functions can be classified into input distance functions and output distance functions. Input distance functions look for a minimal proportional contraction of an input vector, given an output vector, while output distance functions look for maximal proportional expansion of an output vector, given an input vector. In this study, we use output distance functions.

Before we define the distance function we must first define the technology. Let $x_t \in R^N_+$ and $y_t \in R^M_+$ denote, respectively, an (Nx1) input vector and an (Mx1) output vector for period *t* (*t*=1,2,…,). Then the graph of the production technology in period *t* is the set of all feasible input-output vectors, or

$GR_t = \{(x_t,y_t): x_t \text{ can produce } y_t\}$,
(1)

where the technology is assumed to have the standard properties, such as convexity and strong

disposability, described in Fare et al (1994).

The output sets are defined in terms of GRt as:

$P_t(x_t) = \{y_t: (x_t,y_t) \in GR_t\}$.
(2)

The output distance function for period *t* technology, as described in Shephard (1970), is defined on the output set $P_t(x_t)$ as:

$do^t(x_t,y_t) = \inf\{\delta_t: (y_t/\delta_t) \in P_t(x_t)\}$
(3)

where the subscript "o" stands for "output oriented". This distance function represents the smallest factor, δ_t, by which an output vector (y_t) is deflated so that it can be produced with a given input vector (x_t) under period *t* technology.

The productivity change, measured by the MPI, between periods *s* and *t*, can be defined using the period *t* technology as:

$$M_o^t(y_t, y_s, x_t, x_s) = \frac{d_o^t(x_t, y_t)}{d_o^t(x_s, y_s)}$$
(4)

Similarly, the MPI using period *s* technology may be defined as:

$$M_o^s(y_t, y_s, x_t, x_s) = \frac{d_o^s(x_t, y_t)}{d_o^s(x_s, y_s)}$$
(5)

In order to avoid choosing the MPI of an arbitrary period Fare et al (1994) specified the Malmquist productivity change index as the geometric mean of equations 4 and 5:

$$M_o(y_s, y_t, x_s, x_t) = \left[M_o^t(y_s, y_t, x_s, x_t) \times M_o^s(y_s, y_t, x_s, x_t)\right]^{1/2}$$

$$= \left[\frac{d_o^s(y_t, x_t)}{d_o^s(y_s, x_s)} \times \frac{d_o^t(y_t, x_t)}{d_o^t(y_s, x_s)}\right]^{1/2}$$

(6)

The MPI formula in equation 6 can be equivalently rewritten as:

$$M_o(y_s, y_t, x_s, x_t) = \frac{d_o^t(y_t, x_t)}{d_o^s(y_s, x_s)}\left[\frac{d_o^s(y_t, x_t)}{d_o^t(y_t, x_t)} \times \frac{d_o^s(y_s, x_s)}{d_o^t(y_s, x_s)}\right]^{1/2}$$

(7)

The first component of equation 7 measures the output-oriented technical change between period *s* and *t* whilst the second component measures shift in technology between the two periods. For further discussion of the MPI, refer to Coelli, Rao and Battese (1998).

Calculation of the Malmquist Productivity Index

The MPI has been calculated in various ways. These may be classified in two groups: those which require both price and quantity data, and those which only require quantity (panel) data. The price-based method was proposed by Caves, Christensen and Diewert (1982), who showed that if the distance functions are of translog form with identical second order terms and there is no technical and allocative inefficiency, then the Malmquist index can be computed as the ratio of Törnqvist output index and Törnqvist input index.

Fare et al (1994) subsequently showed that the MPI could be calculated without price data, if one had access to panel data. Furthermore, in this instance, the MPI can be decomposed into technical change and catch-up components, as shown in equation (7). Fare et al (1994) used Data Envelopment Analysis (DEA) methods to estimate and decompose the MPI. We now briefly outline their approach.

The Standard Malmquist DEA Method

Given suitable panel data are available, four distance functions must be calculated (hence four linear programs (LPs) must be solved) for each firm, in order to measure Malmquist TFP changes between any two periods, as defined in equation (7). First we define some notation. Let K, N, M and T represent, respectively, the total number of firms, inputs, outputs and time periods in the sample. Let φ denote a scalar, which represents the proportional expansion of output vector, given the input vector. Let $\lambda=[\lambda_1, \lambda_2, \ldots, \lambda_K]'$ denote the (Kx1) vector of constants, which represent peer weights of a firm. Let yit and xit represent the (Mx1) output vector and the (N×1) input vector, respectively, of the i-th firm in the t-th period (t=1,2,…T). Let Yt and Xt represent, respectively, the (MxK) output matrix and (NxK) input matrix in period t, containing the data for all firms in the t-th period. The notation for period s are defined similarly.

The four required LPs are:

$$[\, d_0^t (y_{it}, x_{it})]^{-1} = \max_{\phi,\lambda} \phi$$

Subject to (s.t.)

$$-\phi y_{it} + Y_t\lambda \geq 0$$

$$x_{it} - X_t\lambda \geq 0$$

$$\lambda \geq 0$$

(8)

$$[d_0^s (y_{is}, x_{is})]^{-1} = \max_{\phi,\lambda} \phi$$

s.t.

$$-\phi y_{is} + Y_s\lambda \geq 0$$

$$x_{is} - X_s\lambda \geq 0$$

$$\lambda \geq 0$$

(9)

$$[d_0^t (y_{is}, x_{is})]^{-1} = \max_{\phi,\lambda} \phi$$

s.t.

$$-\phi y_{is} + Y_t\lambda \geq 0$$

$$x_{is} - X_t\lambda \geq 0$$

$$\lambda \geq 0$$

(10)

$$[d_0^s (y_{it}, x_{it})]^{-1} = \max_{\phi,\lambda} \phi$$

s.t.

$$-\phi y_{it} + Y_s\lambda \geq 0$$

$$x_{it} - X_s\lambda \geq 0$$

$$\lambda \geq 0$$

(11)

The above four LPs are very similar to standard DEA LPs. In fact, equations (8) and (9) are standard DEA LPs, which measure the technical efficiency of the i-th firm in the t-th and s-th year, respectively. In equations (10) and (11) the i-th observation from the t-th period is compared to the technology constructed using the period s data, and vice versa. Thus, in these LPs the φ need not to be greater than or equal to one, if technical regress or progress has occurred. The above four LPs are required for each firm (or region in our study) in each pair of adjacent years. Thus, if one has data on K firms over T time periods, one must solve Kx(3T-2) LPs to construct the required firm-level chained indices (Coelli et al., 1998).

Empirical Analysis

Technical Efficiency (TE), change in TE, Technological change and change in Total Factor Productivity (TFP) is calculated by using Data Envelopment Analysis (DEA) and Malmquist TFP Index for selected OECD countries under the assumption of Constant Returns to Scale. The DEAP- XP software programme which is the advanced version of DEAP 2.1 written by Coelli (1996) is used for the calculation of these indexes.

Technical Efficiency

In the calculation of TE indexes, efficient reference borders are determined by using linear programming methods and the selected countries are compared with these efficient borders. If TE of a country is equal to one (TE = 1), it means that the country has perfect TE or it is on the perfect production border. If TE of a country is lower than one (TE < 1), it means that there is an inefficiency. In other words the inefficiency level is 1 – TE. Inefficiency level shows the inefficient using of production factors. If the TE is lower than 1 (if the inefficiency level (1-TE) is bigger than zero), it means that optimal production can not be reached with given inputs under the current technology level or current production level can be reached by using inputs lower than current level so the production factors are unproductive. The lower TE means the lower producing performance for a country.

In table 1, Technical Efficiency Index under the Assumption of Constant Returns to Scale is given. Luxembourg is the only country that has perfect TE (TE=1) in the period of 1980 – 2003. It is the one which determines the best production border for all years. It is called “reference country.” There are other countries which has TE = 1 in different years. These countries had the effect on determining the best production border for different years. However, Luxembourg has the best performance for all years.

United Kingdom (UK) has an impact to determine the best production level in 1980, 1982 and between the period 1999-2002. Italy has an impact to determine the best production level in 1990, 1991 and between the period 1993-2002. Sweden has an impact to determine the best production level between the period 1993-2003. United States (US) has impact to determine the best production level between the period 1988-1992. Denmark has an impact to determine the best production level in 1992, 1994 and between the period 1980-1982. When we look at Turkey, we see that it has an impact to determine the best production border just only in years 1980 and 2003.

If we order the countries from the most technical efficient to the less technical efficient according to the mean of TE for selected period, we can have ordering like that: Luxembourg, UK, Italy, Sweden, US, Denmark, Belgium, Mexico, Netherlands, France, Switzerland, Germany, Austria, Iceland, Ireland, Canada, Norway, Japan, Finland, New Zealand, Spain, Turkey, Greece, Australia, Portugal and Korea (Republic of). The average of the sample data is 0.837 and the Mean of TE for Turkey is below that average (TE = 0.767).

Table 1: Technical Efficiency Index under the Assumption of Constant Returns to Scale

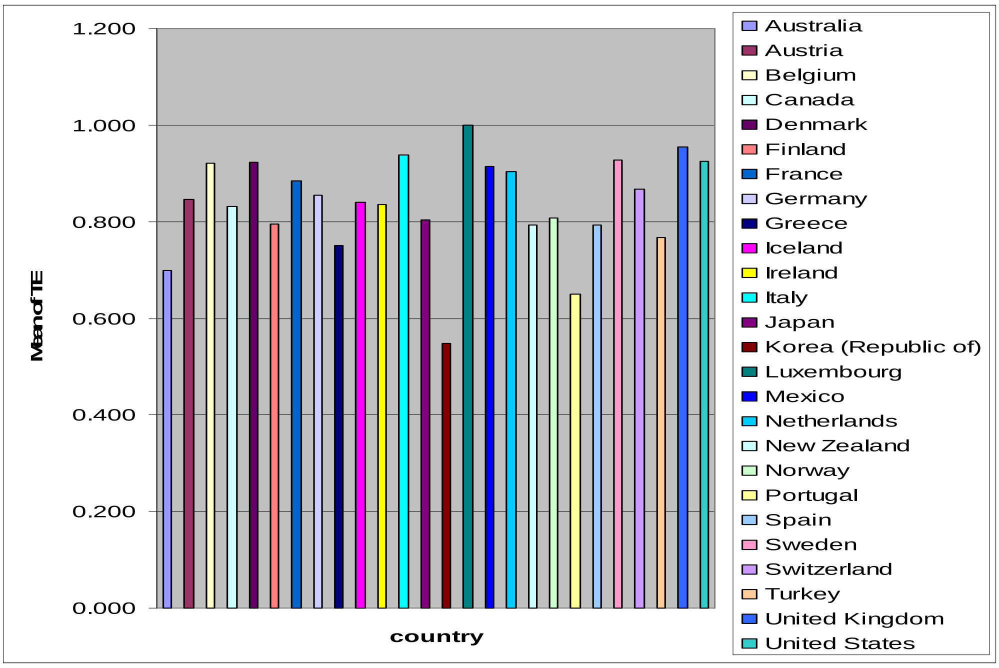
Country/Year	**1980**	**1981**	**1982**	**1983**	**1984**	**1985**	**1986**	**1987**	**1988**	**1989**	**1990**
Australia	0.715	0.603	0.690	0.687	0.673	0.607	0.675	0.669	0.679	0.677	0.769
Austria	0.850	0.787	0.833	0.775	0.785	0.714	0.870	0.914	0.911	0.869	0.909
Belgium	0.884	0.866	0.911	0.961	0.983	0.901	1.000	1.000	0.981	0.905	0.897
Canada	0.829	0.699	0.784	0.814	0.858	0.780	0.840	0.809	0.836	0.811	0.836
Denmark	1.000	1.000	1.000	0.946	0.900	0.770	0.836	0.886	0.955	0.914	0.982
Finland	0.737	0.643	0.658	0.627	0.669	0.621	0.718	0.729	0.747	0.689	0.727
France	0.871	0.822	0.818	0.795	0.834	0.786	0.902	0.911	0.919	0.866	0.900
Germany	0.899	0.846	0.857	0.777	0.800	0.765	0.896	0.937	0.955	0.885	0.877
Greece	0.694	0.639	0.750	0.679	0.834	0.733	0.759	0.782	0.793	0.770	0.755
Iceland	0.767	0.748	0.731	0.756	0.764	0.735	0.903	0.913	0.958	0.920	0.937
Ireland	0.649	0.589	0.670	0.757	0.825	0.870	1.000	1.000	1.000	0.999	0.932
Italy	0.843	0.795	0.809	0.764	0.765	0.735	0.916	0.980	0.986	0.951	1.000
Japan	0.651	0.661	0.653	0.650	0.671	0.726	0.764	0.796	0.918	0.854	0.727
Korea (Republic of)	0.546	0.553	0.568	0.530	0.541	0.515	0.571	0.560	0.585	0.563	0.506
Luxembourg	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Mexico	0.898	1.000	1.000	1.000	1.000	0.881	0.930	0.974	0.960	1.000	0.976
Netherlands	1.000	1.000	1.000	0.922	0.860	0.779	0.917	0.972	0.978	0.905	0.936
New Zealand	0.779	0.697	0.685	0.666	0.648	0.583	0.746	0.727	0.816	0.821	0.885
Norway	0.759	0.722	0.707	0.636	0.645	0.644	0.693	0.721	0.756	0.784	0.882
Portugal	0.613	0.516	0.527	0.542	0.679	0.688	0.743	0.651	0.635	0.647	0.665
Spain	0.870	0.738	0.786	0.784	0.871	0.778	0.847	0.835	0.830	0.770	0.778
Sweden	0.943	0.853	0.888	0.854	0.851	0.766	0.869	0.842	0.836	0.755	0.868
Switzerland	0.875	0.835	0.964	0.929	0.901	0.885	0.864	0.858	0.848	0.747	0.771
Turkey	**1.000**	**0.869**	**0.892**	**0.894**	**0.899**	**0.732**	**0.696**	**0.664**	**0.640**	**0.757**	**0.763**
United Kingdom	1.000	0.985	1.000	0.993	0.940	0.881	0.967	0.912	0.866	0.794	0.851
United States	0.955	0.846	0.917	0.900	0.865	0.808	0.954	0.955	1.000	1.000	1.000
mean	0.832	0.781	0.811	0.794	0.810	0.757	0.841	0.846	0.861	0.833	0.851

Table 1: Technical Efficiency Index under the Assumption of Constant Returns to Scale (continue)

Country/Year	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	Mean	Degree of inefficiency
Australia	0.778	0.757	0.708	0.700	0.718	0.726	0.688	0.698	0.711	0.786	0.740	0.679	0.642	0.699	0.301
Austria	0.867	0.856	0.879	0.867	0.900	0.875	0.857	0.859	0.844	0.834	0.821	0.824	0.826	0.847	0.153
Belgium	0.915	0.909	0.884	0.913	0.924	0.907	0.883	0.890	0.924	0.914	0.895	0.907	0.927	0.920	0.080
Canada	0.853	0.853	0.853	0.824	0.892	0.889	0.804	0.815	0.854	0.905	0.873	0.831	0.794	0.831	0.169
Denmark	0.964	1.000	0.971	1.000	0.972	0.967	0.904	0.881	0.919	0.899	0.867	0.805	0.789	0.922	0.078
Finland	0.781	0.871	0.935	0.990	0.977	0.944	0.868	0.855	0.875	0.857	0.813	0.871	0.856	0.794	0.206
France	0.888	0.900	0.896	0.920	0.930	0.939	0.936	0.953	0.941	0.923	0.898	0.860	0.822	0.885	0.115
Germany	0.839	0.812	0.794	0.802	0.849	0.853	0.840	0.851	0.866	0.856	0.877	0.893	0.882	0.855	0.146
Greece	0.723	0.762	0.768	0.831	0.859	0.830	0.794	0.779	0.756	0.719	0.703	0.693	0.613	0.751	0.249
Iceland	0.898	0.920	0.930	0.956	0.990	0.864	0.839	0.708	0.761	0.746	0.779	0.880	0.738	0.839	0.161
Ireland	0.951	0.963	1.000	0.937	0.908	0.835	0.796	0.777	0.720	0.701	0.749	0.736	0.668	0.835	0.165
Italy	1.000	0.979	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.997	0.938	0.062
Japan	0.833	0.864	0.976	0.965	0.755	0.713	0.740	0.758	0.906	1.000	0.981	0.910	0.802	0.803	0.197
Korea (Republic of)	0.486	0.485	0.515	0.530	0.526	0.517	0.530	0.542	0.585	0.633	0.635	0.573	0.532	0.547	0.453
Luxembourg	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000
Mexico	0.927	0.905	0.915	0.900	0.989	0.905	0.805	0.787	0.808	0.823	0.868	0.857	0.812	0.913	0.087
Netherlands	0.942	0.922	0.889	0.912	0.944	0.916	0.887	0.908	0.814	0.845	0.824	0.800	0.804	0.903	0.097
New Zealand	0.993	0.972	0.845	0.789	0.754	0.778	0.814	0.855	0.881	0.901	0.865	0.808	0.719	0.793	0.207
Norway	0.905	0.916	0.806	0.855	0.859	0.848	0.776	0.704	0.796	1.000	1.000	1.000	0.954	0.807	0.193
Portugal	0.653	0.684	0.701	0.696	0.700	0.695	0.638	0.625	0.645	0.655	0.657	0.670	0.697	0.651	0.349
Spain	0.782	0.810	0.787	0.806	0.807	0.806	0.789	0.779	0.778	0.765	0.745	0.740	0.723	0.792	0.208
Sweden	0.914	0.993	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.926	0.074
Switzerland	0.831	0.819	0.900	0.890	0.887	0.894	0.878	0.867	0.895	0.878	0.873	0.876	0.849	0.867	0.133
Turkey	**0.684**	**0.687**	**0.584**	**0.629**	**0.670**	**0.644**	**0.595**	**0.669**	**0.783**	**0.759**	**0.916**	**0.991**	**1.000**	**0.767**	**0.233**
UK	0.908	0.986	0.990	0.975	0.979	0.982	0.985	0.965	1.000	1.000	1.000	1.000	0.962	0.955	0.045
United States	1.000	1.000	0.938	0.958	0.926	0.913	0.894	0.886	0.880	0.902	0.927	0.927	0.872	0.926	0.074
Mean	0.858	0.870	0.864	0.871	0.874	0.855	0.829	0.824	0.844	0.858	0.858	0.851	0.818	0.837	0.163

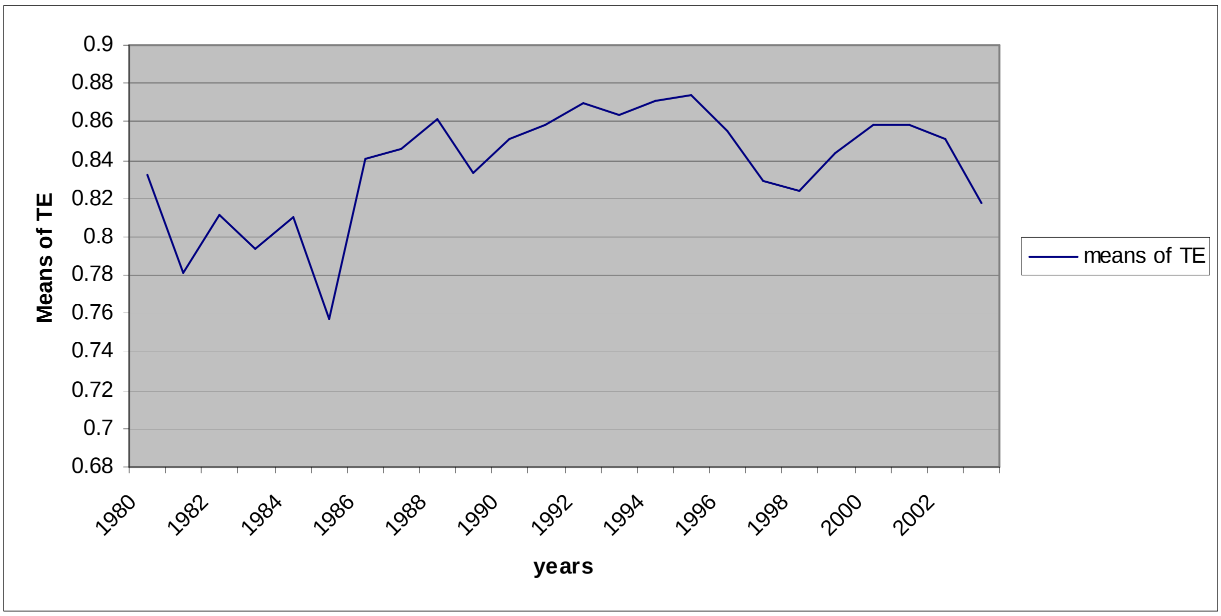
There are exciting results that we cannot expected before for example Korea and Japan which are developed in high levels in last decades has a lower TE in selected period. Korea is the last country according to mean of TE which is equal to 0.547. When we look at the figure 1, we will see that there are 12 countries below the average TE (= 0.837) and 14 over the average. The countries below the average are Australia, Canada, Finland, Greece, Ireland, Japan, Korea, New Zealand, Norway, Portugal, Spain and **Turkey**. However, the countries over the average are Austria, Belgium, Denmark, France, Germany, Iceland, Italy, Luxembourg, Mexico, Netherlands, Sweden, Switzerland, UK and US.

Figure 1: Means of TE



In figure 2, we can see that TE of countries was at its lowest level in 1985 (TE = 0.757) and at its highest level in 1995 (TE = 0.874). Also we can say that there is a relatively sustainable increase in the period between 1985-1995.

Figure 2: Annual Means of TE between 1980-2003



We can conclude that most of the European Union Members are has a TE level over the sample average while Japan and Korea are below the average. However the average level of TE index for the period 1980-2003 is lower than 1 (=0.837). It means that, in selected OECD countries, optimal production can not be reached with given inputs under the current technology level or current production level can be reached by using inputs lower than current level so the production factors are unproductive.

Changes in Total Factor Productivity

If the changes in total factor productivity (TFPCH) index is greater than one (TFPCH > 1) shows that there is an increase in TFP. If the TFPCH is lower than one (TFPCH < 1), it means that there is a decrease in TFP. There are two components of TFP, these are changes in technical efficiency (EFFCH) and changes in technology (TECHCH). If these two indexes are higher than one, it means that there are improvements in both technical efficiency and technology. If they are lower than one, it means that there are decline in both technical efficiency and technology. In another word, if EFFCH index is higher than one (EFFCH > 1), there is a bigger catching – up effect for the country. If TECHCH index is higher than one (TECHCH > 1), it means that production border shifts up.

We can divide EFFCH index into two sub-index called changes in pure efficiency (PECH) and changes in scale efficiency (SECH). SECH index shows the achievement of producing in an appropriate scale.

Decomposition of Malmquist TFP index is useful to determine the sources of the changes in TFP (Deliktaş, 2002:263).

We can see in the table 2 that the annual average value of EFFCH index is 0.999. It means that there is a decreasing in technical efficiency in general. However, there is no decrease in the components of EFFCH. Both the average of PECH and SECH are equal to 1. Although TECHCH index is increased by %1.8, EFFCH index is decreased by %0.1 and also TFPCH index is increased by %1.7 in the period of 1980-2003 for all countries. The increase in TECHCH causes the increase in TFP. In another words, the reason of the improvement in TFP is technological improvement, not the changes in technical efficiency.

The value of EFFCH indexes which belong to Belgium, Finland, Ireland, Italy, Japan, Norway, Portugal and Sweden are higher than one. It means that these countries have higher catching-up effect to reach the optimal production border/frontier. In other words, these countries are successful to catch up the best production border that is determined by the reference country (Luxembourg). The most successful country for catch up is Norway. However Australia, Austria, Canada, Denmark, France, Germany, Greece, Iceland, Korea, Mexico, Netherlands, New Zealand, Spain, Switzerland, UK and USA have EFFCH levels lower than 1. It means that there is no catching – up effect in these countries. In addition, Luxembourg and Turkey have the EFFCH indexes equal to 1. Luxembourg is the reference country and Turkey is stable so Turkey has no success or failure to catch up the best production border. In other words, annual average technical efficiency level of Turkey is not changed.

According to the technological change index (TECHCH), Japan obtains the highest technological improvement in the period of 1980-2003. Switzerland, Norway, Luxembourg, Italy, Netherlands, Spain, Austria, Belgium, Korea, France, Germany, Denmark, US, Sweden, Finland, Portugal, Australia, Canada, Ireland, Iceland, UK, Greece, New Zealand, Mexico and Turkey follow Japan respectively. In that period all countries have the technological improvement and annual average TECHCH index is measured 1.018 and TFPCH index is measured 1.017 for all countries. TECH index is higher than 1, it means that the annual average of best production border is shifted up by technological improvement.

Table 2: Malmquist Index Summary of Country Means

Country	Effch	Techch	Pech	Sech	Tfpch
Australia	0.995	1.012	0.998	0.997	1.007
Austria	0.999	1.023	0.999	1.000	1.022
Belgium	1.002	1.021	1.001	1.001	1.023
Canada	0.998	1.012	0.999	0.999	1.011
Denmark	0.990	1.016	0.990	1.000	1.006
Finland	1.007	1.015	1.007	1.000	1.021
France	0.997	1.019	1.000	0.998	1.017
Germany	0.999	1.018	1.000	0.999	1.017
Greece	0.995	1.010	0.995	1.000	1.004
Iceland	0.998	1.012	1.000	0.998	1.011
Ireland	1.001	1.012	1.001	1.001	1.013
Italy	1.007	1.025	1.004	1.004	1.032
Japan	1.009	1.048	1.008	1.001	1.058
Korea (Republic of)	0.999	1.020	1.004	0.994	1.019
Luxembourg	1.000	1.025	1.000	1.000	1.025
Mexico	0.996	1.003	0.992	1.003	0.999
Netherlands	0.991	1.023	0.994	0.997	1.013
New Zealand	0.996	1.007	0.996	1.000	1.003
Norway	1.010	1.026	1.010	1.000	1.036
Portugal	1.006	1.014	1.006	1.000	1.020
Spain	0.992	1.023	0.991	1.001	1.015
Sweden	1.003	1.016	1.002	1.001	1.019
Switzerland	0.999	1.034	0.996	1.003	1.033
Turkey	**1.000**	**1.002**	**1.000**	**1.000**	**1.002**
United Kingdom	0.998	1.011	1.000	0.998	1.009
United States	0.996	1.016	1.000	0.996	1.012
Mean (geometric)	0.999	1.018	1.000	1.000	1.017

EFFCH: Changes in technical efficiency, TECHCH : Changes in technology, PECH: Changes in pure efficiency, SECH: Changes in scale efficiency, TFPCH: Changes in total factor productivity.

When we look at the TFP of countries, we can see that Japan has the highest increase in annual average TFP. Norway, Switzerland, Italy, Luxembourg, Belgium, Austria, Finland, Portugal, Sweden, Korea, Germany, France, Spain, Ireland, Netherlands, US, Canada, Iceland, UK, Australia, Denmark, Greece, New Zealand, Turkey follow the Japan respectively. Only Mexico has a decrease in its annual average TFP. The source of that decrease is the decreasing in technical efficiency.

Conclusion

The performance of ICT sectors of selected OECD countries are considered by using Data Envelopment Analysis (DEA) for the period of 1980-2003. The levels of technical efficiency, changes in technical efficiency, technological change and the changes in TFP are calculated in this study for all selected OECD countries. Here are the main evidences that we reach as a result of the study.

First of all, according to the results of the technical efficiency index Luxembourg is the reference country (TE = 1) and Korea has the worst performance. Secondly, there are technological improvements in all countries (TECHCH > 1), however there are declines in technical efficiencies (EFFCH < 1). Thirdly, the effect of technological improvement is higher than the effect of declining in technical efficiency, as a result of this, there are positive changes in TFP in all countries except Mexico. According to EFFCH and TFPCH indexes, Turkey is under the average level of selected OECD countries. According to the technological change index (TECHCH), Japan obtains the highest technological improvement and according to EFFCH index, the most successful country for catch up is Norway in the period of 1980-2003.

Most of the European Union Members are has a TE level over the sample average while Japan and Korea are below the average. However the average level of TE index for the period 1980-2003 is lower than 1 (=0.837). It means that, in selected OECD countries, optimal production can not be reached with given inputs under the current technology level or current production level can be reached by using inputs lower than current level so the production factors are unproductive.

There are two ways to improve the TFP of ICT and to improve the power of competitiveness. First of all, if the selected countries solve that inefficiency problem by reallocation of resources, they can improve their TFP of the ICT sector and as a result they can be more competitive. Secondly, the technological improvement in these countries creates an expectation about increasing TFP of ICT sector for future. If there will be a sustainable technological improvement by innovation, it will cause a sustainable increase in the TFP of ICT sector and as a result it will cause a sustainable increase in competitiveness.

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