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Measuring Productivity and Technology Changes in the Islamic Azad University in Iran

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Abstract: The aim of this study is to estimate the productivity and technology changes in the Islamic Azad University (IAU) of Iran. The focus of this study is using a model of Malmquist Productivity Index (MPI). MPI is a body of research methodologies to evaluate overall efficiencies and identify the sources and estimate the amounts of inefficiencies in inputs and outputs. By far the largest single cause of universities' overall technical efficiency is pure technical efficiency, along with a considerable amount of scale inefficiency and a modest amount of Congestion. No obvious regional differences in the universities' productivity growth are apparent between 1999 and 2009. Decomposition of the MPI indicates that although there has been technological progress over the years, poor scale efficiency and technical efficiency have resulted in deterioration in the universities' average productivity.

Keywords: Islamic Azad University, malmqvist productivity index, productivity, technology changes

INTRODUCTION

The word productivity has been used in economic culture since two centuries. In many places of the world especially in industrial countries, productivity is assumed as a thought and culture Productivity is a subject which has been attended from different aspects and its importance is enhanced day by day. It is a common subject of economy and management. As there is limitation of resources and numerable needs of humankinds, increasing of population, and extreme competition in universal economy, so the improvement of productivity is not a choice but a necessity. Undoubtedly, nowadays, economic growth and development of various societies depend on the growth of productivity.

There is a consensus among economists that productivity growth plays a substantial role in enhancing Standards of living and international competitiveness. As higher productivity translates into higher per capita income, individuals benefit from higher standards of health care, better education and public welfare. Romer and Romer (1990) demonstrates the way in which public and private resources devoted to the Development of new ideas and new products can accelerate economic growth and productivity.

On the other hand, the neo-Schumpeterian models of Aghionand and Howitt (1998) analyzed the economic impact of research into product improvement rather than product diversity. Nevertheless their overall conclusions were the same as those of Romer. That is, increase in productivity, brought about by new or improved products and processes, such as information and communication, Their overall conclusions were the same as those of Romer. That is, increase in productivity, brought about by new or improved products and processes, such as Information and Communication Technologies (ICTs), will directly and indirectly result in increased returns to capital investment and consequently lead to a sustained level of growth of GDP. Therefore, it can be stated that the estimates based on growth-accounting procedures underestimate the true contribution of productivity growth. There are various types of the productivity in economic texts where all of them show the appropriate ways of using the sources to achieve the assumed aims. There are three kinds of productivity: Minor Productivity, Total Productivity of Factors and Total Productivity.

Minor productivity: It means the ratio of the output to one of the inputs. For instance, the productivity of labor which is equal to the ratio of output to the labor input and this is a minor productivity scale. Similarly, capital productivity is equal to the ratio of output to the capital stock. Also material productivity is equal to the ratio of output to the material input which is a minor productivity. Total Productivity: it means the ratio of genuine output to the total input of labor expenditure and capital stock. To achieve of genuine output, we should minus the purchased goods and dealing services from the total output. It should be noticed that in this scale only labor and capital stock inputs must be considered.

Total factor productivity: TFP means, the ratio of total output to the collection of all input factors. In this case, total productivity reflects the effects of all inputs on

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output production. In other words, total productivity of production factors is a combined productivity of all inputs. Generally over two centuries, the concept of productivity is defined as the relation between output and input, and applied in different circumstances of various levels of aggregation in the economic system. It is argued that productivity is one of the basic variables governing economic production activities, perhaps the most important one (Singh *et al*., 2000) , However, productivity is often relegated to second rank, and neglected or ignored by those who influence production processes (Tangen, 2002b). A major reason for this could be that many managers do not understand what the term productivity actually means. In fact, productivity is frequently discussed by managers but rarely defined, often misunderstood and confused with similar terms, and seldom measured in an appropriate way, leading to productivity being disregarded due to (Lewis and Koss, 1993) remarkably many managers who makes decisions every day about improving plant efficiency do not know how to answer the simple question: "What do we really mean by Productivity?" Nevertheless, if we do not fully understand what productivity is, how can we decide what productivity measures to use? How can we interpret them correctly? How can we know what actions to take to improve productivity? Evidently, the confusion surrounding the subject makes it necessary to further investigate and emphasize the basic meaning of productivity. Hence, an improper definition of productivity will often result in that action is being misdirected (Forrester, 1993). The term productivity is commonly used within academic and commercial circles; it is however rarely adequately defined or explained. Indeed it is often confused and considered to be interchangeable, along with terms such as efficiency, effectiveness, performance and profitability (Sumanth, 1994). Measurement and improvement regimes are often built without a clear understanding of what is being measured or improved. This can be regarded as simply a pragmatic approach to improvement, or a missed opportunity to fully understand important factors relating to competitiveness and success. Certainly, shared vocabulary and grammar is helpful within academia, for ensuring rigorous and robust development of shared understanding. Over two centuries ago, Quesnay used the term productivity (Hobson, 2004). Since then it has been applied in many different circumstances at various levels of aggregation, and in relation to economic systems (Tangen 2002a). It has been argued that productivity represents one of the most important basic variables governing economic activities (Singh *et al*., 2000). Grossman (1993), for example, discusses productivity improvement as one of the key competitive advantages of an enterprise. Companies need to realize that a gain in productivity is one of their major weapons to achieve cost and quality advantages over their competition. In spite of the fact that productivity is seen as one of the most vital factors affecting competitiveness of economic activities, many researchers argue that productivity is often relegated to second rank, and neglected or ignored by those who influence production processes (Broman, 2004). One reason for this is the lack of common agreement on what the term represents. Though the term widely used, it is often misunderstood, leading to productivity being disregarded or even to contra productive decision making (Sink, 1989). Chew suggests that even though the concept of productivity has existed for a long time, people who make decisions every day about improving plant efficiency do not know how to answer the simple question of what productivity is. This suggests that productivity is a multidimensional term, the meaning of which varies, depending on the context within which it is used. The aim of this study is to estimate the productivity and technology changes in the Islamic Azad University (IAU) of Iran.

LITERATURE REVIEW

Numerous studies have looked in depth at the efficiency and productivity of universities. Measuring efficiency and productivity in public Higher Education Institutions (HEI) provides an indirect evaluation of public funding management informs policy making and improves university productivity and consequently public funding management GARCÍA-ARACIL (2006). Productivity in higher education has an obvious multidimensional character as it relates to both production and dissemination of knowledge through its various activities of teaching, research, and outreach activities (Dundar and LEWIS, 1998). In this sense, measuring productivity in the higher education context is complicated. Changes in productivity growth can be calculated using the Malmquist productivity change index, which is a particularly attractive methodology (Johnes, 2005).

Dowrick and Duc (1990), in his empirical examination of labor productivity in Australia, identified the major determinants of the 1980s productivity slump. His econometric results indicate that slowing down of labor productivity after 1983 was mainly associated with capital dilution, reflecting a small fall in investment as well as a sharp expansion of hours worked between 1983 and 1988. A study done by Hauner (2005) on productivity by using Data Envelopment Analysis (DEA). He found that, there was no evidence to which average productivity would respond to deregulation during the period 1995-1999 among large German and Austrian banks (Hauner, 2005). Amini (2006), measured and analyzed labor, capital, and total factors as mentioned in the Iranian 4th 5-year programme for development from 1991 to 2003. Due to the outcomes the productivity index of labor has increased 0.9% during the mentioned periods in the

economy of Iran. Kong and Tongzon (2006) examined the total factor productivity for ten major sectors of Singapore during 1985-2000. They used the non-parametric, frontier methodology known as data envelopment analysis to calculate the Malmquist Productivity Index at sectoral level. The analysis of the results identified the best practiced sectors and straggler in terms of efficiency change, technical change and total factor productivity change. Afzal (2006) estimated total factor productivity for the large scale manufacturing sector from 1975 to 2001 using three different approaches. Overall results showed that productivity was affected by many factors like labor, capital, gross national product and per capita income. Diaz and Sanchez (2008) analyzed the performance of the small and medium Spanish manufacturing firms during 1995-2001. The findings of the results suggested that small and medium firms are more efficient than large firms. Basti and Akin (2008) compared the productivity of domestic owned and foreign owned firms operating in Turkey. They selected non financial firms listed on Istanbul Stock Exchange for period 2003-2007. The results of the study indicated that there were no differences in terms of productivity of domestic owned and foreign owned firm.

MATERIALS AND METHODS

The methodology used to study productivity growth in Spanish public universities, from 1994 to 2004, is the nonparametric Malmquist index. This productivity growth method is superior to other indexes, such as the Törnqvist index or the Fisher Ideal index, because Malmquist index is based on quantity data only, and makes no assumptions regarding university behavior (Grifell-Tatjé and LOVELL, 1996). Several different decompositions of the Malmquist index have been proposed in the literature. (Fare *et al*., 1994) assume Constant Returns to Scale (CRS) technology; Ray and DESLI (1997) use another decomposition that does not require CRS assumptions. Simar and WILSON (1998) decomposition by further decomposing the technical change component into a "pure" technical change plus a residual measure of the scale change in the technology. This residual measure evaluates the separation between CRS and Variable Returns to Scale (VRS) technologies. In this study, we initially assume CRS and calculate total productivity change, decomposed into technological (or technical) change and technical efficiency change, which includes “pure” efficiency change and scale efficiency change. Furthermore, in applying the Malmquist methodology to study productivity, it is necessary to construct a nonparametric envelopment frontier over the data points, such that all observed points lie on or below the production frontier. There are two analytic options:

Input orientation, which reduces the inputs without dropping the output levels, and output orientation, which raises outputs without increasing the inputs. In terms of education, universities are given a fixed quantity of resources (e.g., state financial resources, academic and non-academic loads) and asked to produce as much output as possible. Thus, we assume an output orientation. The output-based Malmquist productivity change index (M) specified by Fare *et al*. (1994) can be formulated as:

$$M_0^{t+1,t}(y_t, x_t, y_{t+1}, x_{t+1}) = \left[\frac{D_0^t(y_{t+1}, x_{t+1})}{D_0^t(y_t, x_t)} \times \frac{D_0^{t+1}(y_{t+1}, x_{t+1})}{D_0^{t+1}(y_t, x_t)} \right]^{1/2} \quad (1)$$

where, the subscript *O* indicates an output-orientation, M is the productivity of the most recent production point (xt+1, y t+1) (using period t + 1 technology) relative to the earlier production point (xt, yt) (using period t technology), D0 is the output distance function which is the reciprocal of Farrell (1957) technical efficiency measures. The output distance function is defined on the output set *P(x)*, as:

$$D_0(x, y) : \text{Min } \{\theta : (y/\theta) \in P(x) \quad (2)$$

where, θ is the corresponding level of efficiency. The output distance function seeks the largest proportional increase in the observed output vector y provided that the expanded vector (y/θ) is still an element of the original output set (Grosskopf *et al*., 1995). If the university is fully efficient such that it is at the frontier, Do(x, y) = θ = 1, whereas Do(x, y) = θ>1 indicates that the institution is inefficient.

An equivalent way of writing the Malmquist index is:

$$M_0^{t+1,t}(y_t, x_t, y_{t+1}, x_{t+1}) = \frac{D_0^{t+1}(y_{t+1}, x_{t+1})}{D_0^t(y_t, x_t)} \left[\frac{D_0^t(y_{t+1}, x_{t+1})}{D_0^{t+1}(y_{t+1}, x_{t+1})} \times \frac{D_0^t(y_t, x_t)}{D_0^{t+1}(y_t, x_t)} \right]^{1/2} \quad (3)$$

measures the degree of catching up to the best-practice frontier level for each observation between time period *t* and time period t + 1 (term outside the square bracket) and a measure of technical progress P (the two ratios in the square bracket) as measured by shifts in the frontier of technology (or innovation) measured at period t + 1 and period t (averaged geometrically). We can obtain measures of overall technical efficiency (E) and “Pure” Technical efficiency (PT) by applying the same data CRS assumption (without convexity constraint) and VRS (with convexity constraint). Dividing overall technical Efficiency (E) by “Pure” Technical efficiency change (PT) yields a measure of scale efficiency change (S). Recalling that M indicates the degree of productivity change, if M<1 then productivity gains occur, whilst if

M>1 productivity losses occur. Regarding changes in efficiency, technical efficiency increases (decreases) if, and only if, *E* is greater (less) than 1. An interpretation of the technological change index is that technical progress (regress) has occurred if *P* is greater (less) than 1. To calculates the indices, it is necessary to solve several linear programs to maximize the function with the premises. Assume there are N universities and that each university consumes varying amounts of K different inputs to produce M outputs. The ith university is therefore represented by the vectors xiyi and the (K×N) input matrix X and the (M×N)output matrix Y represent the data for all universities in the sample. The first two linear programs are where the technology and the observation to be evaluated are from the same period, and the solution value is less than or equal to unity. The second two linear programs occur where the reference technology is constructed from data in one period, whereas the observation to be evaluated is from another period. The following linear programs are used:

$$[D_0^{t+1}(y_{t+1},x_{t+1})]^{-1} = \max_{\theta,\lambda} \theta \quad \text{s.t } \theta\, y_{i,\,t+1}\, Y_{t+1}\, \lambda \geq 0 \quad x\ i,\ t+1 - X_{t+1}\lambda \geq 0 \quad \lambda \geq 0$$

$$[D_0^{t}(y_t,x_t)]^{-1} = \max_{\theta,\lambda} \theta \quad \text{s.t } \theta\ y_{i,t} + Y_t \geq 0 \quad x_{i,\,t+1} - X_{t+1}\lambda \geq 0 \quad \lambda \geq 0$$

$$[D_0^{t+1}(y_t,x_t)]^{-1} = \max_{\theta,\lambda} \theta \quad \text{s.t } -y_{i,t} + Y_{T+1}\, \lambda \geq 0 \quad x_{i,t} - X_{t+1} \geq 0 \quad \lambda \geq 0$$

$$[D_0^{t}(y_{t+1},x_{t+1})]^{-1} = \max_{\theta,\lambda} \theta \quad \text{s.t } \theta\ y_{i,\,t+1} + Y_t\lambda \geq 0 \quad X_{i,\,y+1} - X_t\lambda \geq 0 \quad \lambda \geq 0 \qquad (4)$$

This approach can be extended by decomposing the CRS technical efficiency change into scale efficiency and "pure" technical efficiency components. Further details on the interpretation of these indices may be found in Charnes *et al*. (1993), Lovell (2003) and Worthington and Lee (2005).

The data used in the present study were collected during 1999-2008 by the project of applied Methods for the Evaluation of the Productivity of IAU Fathi (2011). Data for the academic years 1999 to 2009 for IAU in Iran were collected from various government and institutional sources. We identified variables related to inputs and outputs of interest for this study: fixed capital inventory, compensation of employee service, and value added publications. Data include two inputs and two outputs. Inputs indicate fixed capital inventory and compensation of employee service, and output is value added and publications in IAU.

RESULTS AND DISCUSSION

To evaluate IAU, first, we analyze a "general model" taking as inputs fixed capital inventory, compensation of employee service, and as outputs value added, publications. The Malmquist index and its decompositions for each of the four models are presented in Table 1 by year and by university. Three primary issues are addressed in the computation of the Malmquist indices of productivity growth over the sample period. The first is the measurement of productivity change over the period (column *M* in Table 1). The second is to decompose changes in productivity into what are generally referred to as a "catching-up" effect (technical efficiency change) (column *E* in Table 1) and a "frontier shift" effect (technological change) (column *P* in Table 1). The third is that the "catching-up" effect is further decomposed to identify the main source of improvement, either through enhancements in "pure" technical efficiency (column *PT* in Table 1) or increases in scale efficiency (column *S* in Table 1). Table 1 show that the "general-model" showed an annual mean increase in total factor productivity *(M)* of 4.6% for the period 1999 to 2009 across the university sector. Given that productivity change is the sum of technical efficiency and technological change, the major cause of productivity improvements can be ascertained by comparing the values for efficiency change and technological change. That is, the productivity gains described could be the result of efficiency gains, or technological improvements, or both. In our case, the overall improvement in productivity over the period is composed of an average efficiency increase (movement towards the frontier) of 0.6%, and average technological progress (upward shift of the frontier) of 4.0% annually. Technical efficiency can be further decomposed into "pure" technical efficiency (0.5) and scale efficiency (0.1). Clearly, the IAU sustained improvement in productivity over the period 1999-2009 is the result of a sustained expansion in the frontier relating inputs to outputs, rather than any improvements in efficiency.

Analysis by years, the highest mean productivity improvement was in academic year 2001/2002 with 10.5%, which was composed of 7.9% improvement in efficiency (the highest in the period analyzed) and 2.4% of technological gain. In turn, most of the technical efficiency gain was due to improvements in "pure" technical efficiency (5.6%) and scale efficiency (2.2%). By way of comparison, the high level of technological improvement was spread across the sector in the academic year 2006/2007 (26.2%), but with a fall in efficiency (-16.4%). Focusing on the "teaching-model", Table 1 shows that there was an annual mean increase in total factor productivity *(M)* of 3.8% for the period 1999 to 2009, which was composed of an improvement in technological change (4.0%) and a fall in technical efficiency change (-0.2%). It could be said that the improvement in teaching only productivity in IAU has been sustained by the expansion in the frontier rather than by improvements in efficiency. With regard to the "research-model", Table 1 shows that the annual mean increase in research only productivity was 9.5% for the period 1999 to 2009, which was composed of average efficiency increase of 5.7%, and average technological

Table 1: Malmquist index by year and by IAU

	General model					Teaching model					Model research				
Year	E	P	PT	S	M	E	P	PT	S	M	E	P	PT	S	M
1999-2000	4.6	-1.2	4.2	0.4	3.4	4.2	-1.4	4.8	-0.6	2.8	8.4	3.0	7.7	0.6	11.6
2000-2001	2.7	4.3	4.3	-1.5	7.1	0.7	6.0	2.5	-1.7	6.7	-1.1	8.5	4.9	-5.7	7.2
2001-2002	7.9	2.4	5.6	2.2	10.5	12.8	-2.6	7.2	5.2	9.8	19.1	-5.2	13.8	4.7	12.8
2002-2003	0.8	7.5	-4.0	5.0	8.4	-2.8	10.1	-5.8	3.2	7.0	0.7	17.0	0.6	0.1	17.7
2003-2004	1.0	-0.3	1.6	-0.6	0.7	2.8	-3.5	2.7	0.1	-0.8	10.0	0.2	6.7	3.1	10.2
2004-2005	-1.2	2.1	0.2	-1.4	0.9	0.6	-0.5	2.0	-1.4	0.0	-4.2	6.5	-5.8	1.7	2.0
2005-2006	7.6	-6.0	3.2	4.3	1.1	5.8	-5.9	3.4	2.3	-0.4	13.8	-3.5	7.2	6.2	9.9
2006-2007	-16.4	26.2	-10.2	-6.9	5.5	-21.7	35.1	-15.2	-7.7	5.7	1.5	3.8	4.2	-2.7	5.3
2007-2008	-21.3	33.6	-14.4	-8.0	5.1	-11.8	6.5	-6.0	-6.2	-6.0	13.9	-4.0	8.9	4.7	9.3
2008-2009	-5.8	4.1	-6.1	0.3	-2.0	37.3	-38.1	21.7	12.8	-15.0	6.8	-9.6	8.0	-1.1	-3.4
All year	0.6	4.0	0.5	0.1	4.6	-0.2	4.0	0.0	-0.1	3.8	5.7	3.6	4.8	0.9	9.5

progress of 3.6% annually. The increment for technical efficiency can be decomposed into "pure" technical efficiency (4.8%) and scale efficiency (0.9%). It seems that IAU improvements in research only productivity are sustained by both expansions in the frontier and movement towards the efficiency frontier. In the analysis by years, the highest mean research only productivity was in the academic year 2002/2003 with 17.7%, which was composed of 0.7% improvement in efficiency and 17.0% in technological gain. The lowest increase in research only productivity was in the academic year 2004/2005 with a 2.0%.

CONCLUSION

This paper makes a tripartite contribution. First, it represents the first analysis of the efficiency and productivity of IAU, Iran. Second, it is the first analysis of the contribution differing institutional structure makes to relative efficiency in the IAU. In this paper, we have examined the productivity of IAU from 1999 to 2009, applying the Malmquist Productivity Index to illustrate the contribution of efficiency and technological change to productivity change over the period. The results indicate that annual productivity growth was largely attributable to technological progress rather than efficiency improvements. Focusing on the "teaching-model", shows that there was an annual mean increase in total factor productivity (M) of 3.8% for the period 1999 to 2009, which was composed of an Improvement in technological change (4.0%) and a fall in technical efficiency change (-0.2%). Gains in scale efficiency appear to have played only a minor role in productivity gains. The fact that technical efficiency contributes little suggests that most universities are operating near the best practice frontier.

REFRENCES

Afzal, M., 2006. Some new production measurement methods for large-scale manufacturing sector of Pakistan. Ph.D. Thesis, (unpublished) submitted to National College of Business Administration and Economics.

Aghionand, P. and P. Howitt, 1998. Howitt, Endogenous Growth Theory. University of Cambridge, MIT Press, MA.

Amini, A., 2006. The calculation and the analysis of the trend of the indexes of the productivity to divide the major parts of the economy of Iran. The office of the Economy of Iran.

Broman, M., 2004. Assessing productivity in assembly systems. Licentiate Thesis, Department of Production Engineering, the Royal Institute of Technology, Stockholm.

Basti, Y. and A. Akin, 2008. The comparative productivity of the foreign-owned companies in Turkey. Int. Res. J. Finance Econ., 22: 1450-2887.

Charnes, A., W.W. Cooper, A.Y. Lewin and L.M. Seiford, 1993. Data Envelopment Analysis: Theory, Methodology and Applications. Kluwer Academic Publishers, Mass, Norwell.

Dowrick, S. and T.N. Duc, 1990. OECD comparative economic growth 1950-85: Catch-up and convergence. Am. Econ. Rev., 79: 1010-1030.

Diaz, M.A. and R. Sanchez, 2008. Firm size and productivity in Spain: A stochastic frontier analysis. Small Bus. Econ., 30: 315-323.

Dundar, H. and D.R. Lewis, 1998. Determinants of research productivity in higher education. Res. Higher Educ., 39(6): 607-631.

Fathi, B., 2011. Measuring Total Factor Productivity Growth and Technology Changes of Islamic Azad University. Research Project, IAU, Aligoudarz Branch.

Fare, R., S. Grosskopf, M. Norris and Z. Zhang, 1994. Productivity growth, technical progress and efficiency change in industrialized countries. Am. Econ. Rev., 84: 66-83.

Farrell, M.J., 1957. The measurement of productivity efficiency. J. Royal Stat. Soc. A. General, 120: 253-289.

Forrester, J.W., 1993. Low productivity: It is a Problem or Merely a Symptom? Handbook for Productivity Measurement and Improvement. Productivity Press, Cambridge.

Grossman, E., 1993. How to Measure Company Productivity. Productivity Press, Cambridge, MA.

García-Aracil, 2006. A Overview of Regional Differences in the Spanish Higher Education System. In: Bonaccorsi, A. and D. Cinzia (Eds.), Universities and Strategic Knowledge Creation. Edward Elgar Publishing Ltd., UK.

Grosskopf, S., D. Margaritis and V. Valdmanis, 1995. Estimating out put substitutability of hospital services: A distance function approach. Eur. J. Oper. Res., 80(3): 575-587.

Grifell-Tatjé, E. and C.A.K. Lovell, 1996. A generalized Malmquist productivity index. Top, 7(1): 81-101.

Hobson, J.M., 2004. The Eastern Origins of Western Civilization. Cambridge University Press, Cambridge.

Hauner, D., 2005. Explaining efficiency differences among large German and Austrian banks. Appl. Econ., 37: 969-980.

JOHNES, J., 2005. Efficiency and Productivity Change in the English Higher Educational Sector from 1996/97 to 2002/03.Retrieved from: http:// www. lums. lancs. ac.uk/publications.

Kong, N. and J. Tongzon, 2004. Estimating total factor productivity growth in Singapore at sectoral level using data envelopment analysis. Appl. Econ., 38: 2299-2314.

Lewis, D.A. and E. Koss, 1993. Productivity or efficiency-measuring what we really want. National Prod. Rev., 12: 273-295.

Lovell, C.A.K., 2003. The decomposition of malmquist productivity indexes. J. Prod. Anal., 20: 437-458.

Ray, S.C. and E. Desli, 1997. Productivity growth, technical progress and efficiency change in industrialized countries: Comment. Am. Econ. Rev., 87(5): 1033-1039.

Romer, P. and M. Romer, 1990. Endogenous technological change. J. Polit. Econ., 98: 71-102.

Simar, L. and P. Wilson, 1998. Productivity Growth in Industrialized Countries. Discussion Paper 9810, Institut de Statistique, Université Catholique de Louvain, Belgium.

Singh, H., J. Motwani and A. Kumar, 2000. A review and analysis of the state-of-the-art research on productivity measurement. Ind. Manage. Data Syst., 100(5): 234-241.

Sink, D.S., 1989. Planning and Measurement in your Organization of the Future. Industrial Engineering and Management Press, Norcross, GA, pp: 170-184.

Sumanth, D., 1994. Productivity Engineering and Management. McGraw-Hill, New York.

Tangen, S.A., 2002a. Theoretical foundation for productivity measurement and improvement of automatic assembly systems. Licentiate Thesis, Stockholm: Royal Institute of Technology, 3: 19-30.

Tangen, S.A., 2002b. Understanding the concept of productivity. Proceedings of the 7th Asia Pacific Industrial Engineering and Management Systems Conference, Taipei, Taiwan, 18-20 December.

Worthington, A.C. and B.L. Lee, 2005. Efficiency, technology and productivity change in Australian universities 1998-2003. Working Paper 05/01, University of Wollongong School of Accounting and finance.