TOTAL FACTOR PRODUCTIVITY CHANGE IN NON-BANK FINANCIAL INSTITUTIONS: EVIDENCE FROM MALAYSIA APPLYING A MALMQUIST PRODUCTIVITY INDEX (MPI)

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Abstract. Applying a non-parametric Malmquist Productivity Index (MPI) method, this paper attempts to investigate productivity changes of Malaysian non-bank financial institutions during the post crisis period of 2000-2004. Our results suggest that: (1) Malaysian NBFIs have exhibit productivity regress of 2.3% and that the productivity regress during the period was largely attributed to Technological Change (-5.9%) rather than Technical Efficiency Change (+5.1%). (2) 60% of Malaysian NBFIs have exhibit productivity regress ranging from 1.3% to as high as 45.8% and (3) PTE has greater positive impact to Malaysian NBFIs Technical Efficiency, which congregates to earlier findings by Krishnasamy et al. (2004) on Malaysian banks.

JEL Classification: G21; D24

Keywords: Non-Commercial Bank Financial Intermediaries, Productivity Change, Malmquist Productivity Index, Malaysia

1.Introduction

Given the substantial task of a non-bank financial sector, it is worth raising the issue of why it matters. In particular, since Gerschenkron (1962) classic study emphasized the role of the banking systems in the economic development of Germany, France and Italy in the nineteenth century, it may appear that the need for a non-bank financial sector is largely redundant in the specific circumstances of the developing economies. However, there are two main reasons why the existence of Non-Bank Financial Institutions (NBFIs) matters: one concerns economic development and the other relates to financial stability.

In the first place, banks offer assets (deposits) that claim to be capital certain. If this promise is to be honored, then there must be limits to the range and nature of assets that a bank can reasonably take on to its balance sheets. Notwithstanding the existence of universal banking in many parts of the world, (that is, banks also engaged in securities market activities), this consideration implies that bank-based financial system will tend to have a smaller range of equity-type assets than those with a more broadly based structure including a wide range of NBFIs. More generally, NBFIs play a range of roles that are not suitable for banks and through their provision of liquidity, divisibility, informational efficiencies and risk pooling services they broaden the spectrum of risks available to investors. In this way, they encourage and improve the efficiency of investment and savings. Through the provision of a broader range of financial assets that unlike deposits, are not capital certain, they also foster a risk management culture by encouraging those who are least able to bear risk and fill the gaps in financial services that otherwise occur in bank-based financial systems. Secondly, from the view of financial stability, in financial sectors in which NBFIs are comparatively undeveloped, banks will inevitable be

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required to assume risks that otherwise might be borne by the stock market, collective investment schemes or insurance companies. However, as already noted, there is basic incompatibility between the kinds of financial contract banks offer and their performance of these other financial institutions. Banks may thus become more likely to fail as a result.

One way of minimizing financial fragility in the developing economies may be to encourage a diversity of financial markets and institutions, where investors are able to assume a variety of risks outside the banking system itself. Without this diversity, there is a tendency for all risks to be bundled within the balance sheet of the banking system, which arguably makes severe financial crises more likely. This point was widely noted by policymakers in their analysis of the lessons of the Asian currency crisis, for instance. As Greenspan (1999) pointed, the impact of the currency crisis in Thailand might have been significantly less severe if some of the risks borne by the Thai banks had instead been borne by the capital markets. Thus, there are very good reasons to perform studies on the non-bank financial sector in parallel with the banking system with regards to the efficiency and productivity.

The importance to investigate the efficiency and productivity of Malaysian NBFIs could be best justified by the fact that in Malaysia, the NBFIs played an important role in complementing the facilities offered by the commercial banks. The existence of BFIs and NBFIs supported by efficient money and capital markets keeps the financial sector complete and enhance the overall growth of the economy. Although Malaysia is moving towards a full market based economy, its capital markets are still at its infancy. As sophisticated and well-developed capital market is considered as the hallmark for a market based economy worldwide, study in this nature is particularly important as the health and developments of the capital market is largely relied upon the health of the NBFIs as the NBFIs are the key players in the development of the capital market in Malaysia. Hence, efficient and productive NBFIs are expected to enhance the Malaysian capital markets in its pursuit to move towards a full market based economy.

By applying the non-parametric Malmquist Productivity Index (MPI) methodology, we attempt to investigate the sources of productivity change of Malaysian non-bank financial institutions during the post crisis period of 2000-2004. Our study is confined to the 20 NBFIs, which was issued a license by the central bank of Malaysia, Bank Negara Malaysia (BNM) up to 2004 under the Banking and Financial Institutions Act, 1989 (BAFIA). The NBFIs in Malaysia consists primarily the finance companies and merchant banks. The paper is also aimed to fill a demanding gap in the literature on efficiency and productivity of Malaysian financial institutions by providing the most recent evidence on the productivity changes of Malaysian NBFIs. This paper is set out as follows: The next section will provide a brief overview of the Malaysian financial system. Section 3 reviews the main literature. Section 4 outlines the approaches to the measurement and estimation of productivity change. Section 5 discusses the results and Section 6 concludes.

2. Brief Overview of the Malaysian Banking System

The Malaysian financial system can broadly be divided into the banking system and the non-bank financial intermediaries. These two banking institutions are different with respect to their activities. For a well functioning financial market along with the BFIs, NBFIs have an important role to uplift the economic activity. These two financial sectors can simultaneously build up and strengthen the financial system of the country. The banking system is the largest component, accounting for approximately 70% of the total assets of the financial system. The banking system can be further divided into three main groups namely the commercial banks, finance companies and the merchant banks. The commercial banks are the main players in the banking system. They are the largest and most significant providers of funds in the banking system. As at end-2003, there are 10 domestically incorporated and 13 locally incorporated foreign commercial banks in Malaysia.

Legally, Malaysian commercial banks enjoy the widest scope of permissible activities and are able to engage in a full range of banking services. Traditionally, Malaysian commercial banks main functions includes retail banking services, trade financing facilities, treasury services, cross border payment services and custody services. Apart from the more traditional activities, Malaysian commercial banks are also allowed to engaged in foreign exchange activities i.e. to buy, sell and lend in foreign currencies and the only financial institutions allowed providing current account facilities. Finance companies formed the second largest group of deposit taking institutions in Malaysia. There were 10 domestically incorporated finance companies in Malaysia as at end-2003. Traditionally, finance companies specialize in consumption credit, comprising mainly of hire purchase financing, leasing, housing loans, block discounting and secured personal loans. The finance companies are allowed to accept savings and fixed deposits from the public, but are prohibit from providing current account facilities. They are also not allowed to engage in foreign exchange transactions compared to the commercial banks. During the later part of the last decade, the finance companies began to expand its traditional role in retail financing to include wholesale banking as well. Merchant banks emerged in the Malaysian banking scene in the late 1970s, marking an important milestone in the development of the financial system alongside of the corporate development of the country. As the country's small businesses prospered and grew into large corporations, the banking needs of the nation became larger and more sophisticated, requiring more bulk financing and complex banking services. Merchant banks filled the need for such services by complementing the facilities offered by commercial banks which were at times more focused on providing short-term credit for working capital and trade financing. They play a role in the short-term money market and capital raising activities including financing, specializing in syndication, corporate finance and management advisory services, arranging for the issue and listing of shares as well as investment portfolio management. As of end-2003, there were 10 merchant banks in Malaysia and all are domestically controlled institutions. Despite having undergone tremendous development over the past decades, to the best of our knowledge, there is currently no microeconomic study performed in this area of research with respect to the Malaysian NBFIs. Hence, this study would be the first to provide important insights into the total factor productivity change among Malaysian NBFIs.

3. Related Studies and Methodology

Related Studies. Over the last decade, there has been considerable amount of research performed to study the productivity changes in the commercial banking industry aimed at informing regulators and practitioners faced with a changing environment in the banking industry (Casu *et al*., 2004). During the 1980s and early 1990s, liberalization of the banking sector and increasing number of bank failures has also contributed to increased academic interest in the topic. However, earlier studies have mainly concentrated on the developed countries banking industry, and a few Pacific Basin countries banking sector in the latter part of the last decade. Berg *et al.* (1992) was among the first to investigate productivity change in the banking industry. Using a sample of 346 banks in Norway over 1980-1989, they found that productivity declined at the average bank prior to the period of experiencing deregulation but grew rapidly when deregulation took place. Berg *et al.* (1993) expanded the study by Berg *et al.* (1992) to include Finnish and Swedish banking industries in their studies. They employed the Malmquist approach and used data from a single year in making cross-country comparisons. Among the earlier researcher on banks' productivity performed on Asian countries were by Fukuyama (1995). Fukuyama (1995) studied the nature and extent of technical efficiency and productivity growth of Japanese banks during the 1989 to 1991 period. He further investigates the relationship between efficiency measures, productivity indexes, organizational status and bank size. He found that during the early part of the studies, Japanese banks mean values of the three productivity change indexes were greater compared to the latter part, which he attributed to the collapse of the bubble in Japanese economy. He also found that during the period of study, productivity gains were largely attributed to technological rather than technical efficiency change.

On the other hand, he suggested that the major contribution to productivity losses was resulted by technical efficiency rather than technological regress. Despite substantial studies performed on the developed economies banking industry with regard to the efficiency and productivity of financial institutions, there are only a handful of studies performed on the Malaysian banking industry partly due to the lack of available data sources and the small sample of banks. As pointed by Kwan (2003), the reason for the lack of research on the efficiency of Asian banks is due to the lack of publicly available data for non-publicly traded Asian financial institutions. The most notable research conducted on Malaysian banks' productivity are by Krishnasamy *et al.* (2004) and Sufian and Ibrahim (2005). Krishnasamy *et al.* (2004) investigated Malaysian banks post-merger productivity changes. Applying two inputs, namely labor and total assets and loans and advances and total deposits as outputs, they found that during the period of 2000-2001, post-merger Malaysian banks has achieved a total factor productivity growth of 5.1%. They found that during the period, eight banks posted positive total productivity growth ranging from 1.3% to 19.7%, one bank exhibit total factor productivity regress of 13.3% and a bank was stagnant. The merger has not resulted in better scale efficiency of Malaysian banks as all banks exhibits scale efficiency regress with exception of two banks. The results also suggest rapid technological change of post-merger Malaysian banks ranging from 5.0% to 16.8%. Two banks however experienced technological regress during the period of study. More recently, Sufian and Ibrahim (2005) applied the Malmquist Productivity Index method to investigate the extent of off-balance sheet (OBS) items in explaining Malaysian banks total factor productivity changes. They found that the inclusion of OBS items resulted in an increase in the estimated productivity levels of all banks in the sample during the period of study. They also suggest that the impacts are more pronounced on Malaysian banks technological change rather than efficiency change.

Methodology. Three different indices are frequently used to evaluate technological changes: the Fischer (1922), Tornqvist (1936), and Malmquist (1953) indexes. According to Grifell-Tatje and Lovell (1996), the Malmquist index has three main advantages relative to the Fischer and Tornqvist indices. Firstly, it does not require the profit maximization, or the cost minimization, assumption. Secondly, it does not require information on the input and output prices. Finally, if the researcher has panel data, it allows the decomposition of productivity changes into two components (technical efficiency change or catching up, and technical change or changes in the best practice). Its main disadvantage is the necessity to compute the distance functions. However, the Data Envelopment Analysis (DEA) technique can be used to solve this problem. Following Fare *et al.* (1994) and Fukuyama (1995) among others, the output oriented Malmquist productivity change index will be adopted for this study. Output orientation refers to the emphasis on the equi-proportionate increase of outputs, within the context of a given level of input. The output based Malmquist productivity change index may be formulated as:

$$M_j^{t+1}(y^{t+1},x^{t+1},y^t,x^t)=\left[\frac{D_j^t(y^{t+1},x^{t+1})}{D_j^t(y^t,x^t)}\times\frac{D_j^{t+1}(y^{t+1},x^{t+1})}{D_j^{t+1}(y^t,x^t)}\right]^{1/2} \quad (1)$$

where M is the productivity of the most recent production point (x_t+1, y_t+1) relative to the earlier production point (x_t, y_t). D's are output distance functions. A value greater than unity will indicate positive factor productivity growth between two periods. Following Fare *et al.* (1993) an equivalent way of writing this index is:

$$M^{t+1}{}_j(y^{t+1},x^{t+1},y^t,x^t)=\frac{D_j^{t+1}(y^{t+1},x^{t+1})}{D_j^t(y^t,x^t)}\times\left[\frac{D_j^t(y^{t+1},x^{t+1})}{D_j^{t+1}(y^{t+1},x^{t+1})}\times\frac{D_j^t(y^t,x^t)}{D_j^{t+1}(y^t,x^t)}\right]^{1/2} \quad (2)$$

or $M = TE \times TC$

$$\text{where Technical Efficiency } (TE) = \frac{D_j^{t+1}(y^{t+1},x^{t+1})}{D_j^t(y^t,x^t)} \quad (3)$$

$$\text{Technical Change } (TC) = \left[\frac{D_j^t(y^{t+1},x^{t+1})}{D_j^{t+1}(y^{t+1},x^{t+1})}\times\frac{D_j^t(y^t,x^t)}{D_j^{t+1}(y^t,x^t)}\right]^{1/2} \quad (4)$$

where M is the product of a measure of technical progress TC as measured by shifts in the frontier measured at period t+1 and period t and a change in efficiency TE over the same period. In order to calculate these indices it is necessary to solve several sets of linear programming problems (see Annex)

4. Data, Input and Output Definitions, and Results

Data. For the empirical analysis, *all* Malaysian non-commercial bank financial institutions from 2000 to 2004 will be incorporated in the study. Due to homogeneity constraints, Malaysian Islamic banks and development financial institutions will not be included in the sample of the analysis. Annual data is sourced from published balance sheet information in annual reports of each individual institution. Variable definition is one of the most difficult tasks in banking studies. There is consensus concerning the fact that banking firm is a multi-product organization. However, there is also some disagreement on what banks produce and how to measure bank production. The final decision depends on the underlying concept of a bank, the problem at stake and the availability of information. The approach of input and output definition used in this study is a variation of the intermediation approach, which was originally developed by Sealey and Lindley (1977). The intermediation approach posits total loans and interest income as outputs, whereas deposits along with physical capital are defined as inputs. According to Berger and Humphrey (1997), the intermediation approach might be more suitable for studying efficiency of the entire financial institutions. Furthermore, Sathye (2001) also noted that this approach is more relevant to financial institutions as it is inclusive of interest expenses, which often accounts for one-half to two-thirds of total costs depending on the phase of the interest rate cycles. The aim in the choice of variables for this study is also to provide a parsimonious model and to avoid the use of unnecessary variables that may reduce the degree of freedom. Accordingly, we model Malaysian NBFIs as multi-product firms, producing 2 outputs and employing 2 inputs. All variables are measured in millions of Ringgit. The input vector includes (*x1*) *Total Deposits*, which includes deposits from customers and other banks and (*x2*) *Interest Expenses* while (*y1*) *Total Loans*, which includes loans to customers and other banks and (*y2*) *Interest Income* are the output vectors. The variables selected for this study could be argued to fall under the intermediation approach to modeling bank behavior. The summary of data used is presented in Table 1 in the Annex.

Results. We will discuss the productivity change of Malaysian NBFIs, measured by the Malmquist Total Factor Productivity (TFP) Index and assign the change in total factor productivity to technological and/or technical change. We also attempt to attribute any change in Technical Efficiency (TE) to change in Pure Technical Efficiency (PTE) and/or Scale Efficiency (SE) change. The summary of annual means of Total Factor Productivity Change (Malmquist), Technological Change (TC), Technical Efficiency Change, and its decomposition into Pure Technical Efficiency Change and Scale Efficiency Change for the year 2000-2004 is presented in Table 2. All indices are relative to the previous year and hence the output begins with the year 2001. As depicted in Table 2, the Malmquist results suggest that during the period of 2000-2004, Malaysian NBFIs have exhibit productivity regress of 2.3%. With the exception for the year 2001 and 2004, our results suggest that Malaysian NBFIs have reported productivity decline of 18.8% in the year 2002 and 1.4% in 2003. It is clear from Table 2 that, Malaysian NBFIs have exhibit productivity advancement of 1.3% in 2001 relative to the year 2002 and 9.5% in 2004 relative to 2003. It is also clear from Table 2 that the productivity regress during the period of study was largely attributed to TC regress (-5.9%). During the period of study, our results suggest that Malaysian NBFIs have recorded advancement in TE of 5.1%. From Table 2 it is also apparent that Malaysian NBFIs have exhibit TC regress for the year 2002 (-30.0%) and 2003 (-7.7%). On the other hand, TE has resulted in productivity regressed only in 2004 (-2.9%). The decomposition of TE into its PTE and SE components depicts clear findings. It is clear from Table 2 that PTE has largely resulted in Malaysian NBFIs TE progress. During the period of study, our results suggest that Malaysian NBFIs have exhibit PTE progress especially during the latter part of the period. It could be argued that the intensification of competition among the domestic banking sector has resulted in the increase in PTE of Malaysian NBFIs during the later part of our studies. Our results suggest that, Malaysian NBFIs have exhibit slight improvement in SE during the period of study.

It is clear from Table 2 that, with the exception of the year 2004, Malaysian NBFIs have exhibit SE progress ranging from 0.3% in 2001 to 1.7% in 2003. We now turn to discuss Malaysian NBFIs specific behavior during the period of study. From Table 3, it is clear that during the period of study, about 60% of Malaysian NBFIs have exhibit productivity regress ranging from 1.3% (AFB) to as high as 45.8% (MIM). On the other hand, during the period of study we found that, 8 Malaysian NBFIs have exhibit productivity progress ranging from 2.7% (CIB) to as high as 60.2% (PMB). Our results also suggest that while Malaysian NBFIs on average have reported TC regress, five NBFIs have exhibit TC progress. On the other hand, our results suggest that, 14 or 70% of Malaysian NBFIs have exhibit TE progress, a NBFI was stagnant and 5 NBFIs have reported regress in TE during the period of study.

Table 2: **Malmquist Index Summary of Annual Means**

Year	Technical Efficiency Change (CU)	Technological Change (TC)	CU Decomposition		Total Factor Productivity Change (Malmquist)
			Pure Technical Efficiency Change	Scale Efficiency	
2000	1.000	1.000	1.000	1.000	1.000
00-01	1.001	1.011	0.999	1.003	1.013
01-02	1.161	0.700	1.063	1.092	0.812
02-03	1.069	0.923	1.051	1.017	0.986
03-04	0.971	1.128	1.007	0.964	1.095
Mean	**1.051**	**0.941**	**1.030**	**1.019**	**0.977**

* Figures are mean of every year for all banks[1].

Table 3: **Malmquist Index Summary of NBFI's Means**

Bank	(CU)	(TC)	CU Decomposition		Total Factor Productivity Change (Malmquist)
			Pure Technical Efficiency Change	Scale Efficiency Change	
AMB	1.117	1.003	1.150	0.975	1.112
AFB	1.043	0.952	1.021	1.024	0.987
ALF	0.951	0.972	0.984	0.967	0.916
ALM	1.122	0.979	1.113	1.011	1.067
AMF	1.023	0.932	1.000	1.023	0.949
AMM	1.127	0.981	1.096	1.042	1.102
ASM	1.149	1.036	1.104	1.035	1.163
BCF	0.987	0.985	1.000	0.987	0.973
CIB	1.027	1.021	1.059	1.003	1.027
EFB	1.072	0.886	1.021	1.050	0.949
HLF	0.989	0.977	0.997	0.992	0.959
MIM	0.886	0.466	0.890	0.994	0.542
MFB	0.999	0.943	1.000	0.999	0.934
PFB	1.000	0.853	1.000	1.000	0.853
PMB	1.689	0.961	1.308	1.371	1.602
RDF	1.009	0.946	1.017	0.991	0.956
RSM	1.150	1.015	1.052	1.110	1.151
SFB	1.031	0.910	1.020	1.011	0.938
SIB	1.084	1.086	1.000	1.084	1.160
UMB	1.087	0.925	1.144	0.950	0.944

[1] For the purpose of the study, we have computed four separate frontiers; 2001 relative to 2000, 2002 relative to 2001, 2003 relative to 2002 and 2004 relative to 2003. For brevity purposes, the results are not reported here, but are available from the authors upon request.

Turning now to discuss the decomposition of TE into its PTE and SE components depicts clear findings. During the period of study, our results suggest that, 12 NBFIs have reported PTE progress, 3 NBFIs recorded PTE regress, while 5 NBFIs have remained stagnant. The SE decomposition on the other hand suggest that, 11 NBFIs have reported progress in SE, 8 NBFIs exhibit SE regress, while a NBFI remained stagnant. In congregate to the results by Krishnamsamy *et al.* (2004), which suggest that PTE has largely contributed to Malaysian banks Technical Efficiency progress, we find similar results for Malaysian NBFIs during the period of 2000-2004, which suggest that PTE has greater positive impact to Malaysian NBFIs TE especially during the early part of the studies.

5. Conclusions

Applying a non-parametric Malmquist Productivity Index (MPI) method, this paper attempts to investigate the productivity changes of Malaysian non-commercial banks financial intermediaries (NBFIs) during the post crisis period of 2000-2004. Our results suggest that during the period of 2000-2004, Malaysian NBFIs have exhibit productivity regress of 2.3% and that the productivity regress during the period of study was largely attributed to Technological Change (TC) regress of 5.9% rather than Technical Efficiency (TE), which increased by 5.1% during the period of study. The decomposition of Technical Efficiency into its Pure Technical Efficiency (PTE) and Scale Efficiency (SE) suggest that PTE has largely resulted in Malaysian NBFIs Technical Efficiency progress during the period of study. Our results suggest that Malaysian NBFIs have exhibit PTE progress especially during the latter part of the period, which could be argued to have caused by the intensification of competition among the domestic banking sector during the later part of our studies. Our results also suggest that during the period of study, Malaysian NBFIs have exhibit slight improvement in SE of 1.9%, particularly during the early years. However, during the later part, Malaysian NBFIs have exhibit SE regress.

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Annex

Table 1: **Descriptive Statistics for Inputs and Outputs (units RMb)**

			2000	2001	2002	2003	2004
Otuputs	*Total Loans*	Min	172.0	179.4	136.7	89.8	136.6
		Mean	4,063.3	4,203.4	5,093.2	5,088.2	5,259.3
		Max	14,045.9	17,097.1	22,909.0	25,160.4	26,048.9
		S.D	4,029.5	4,751.1	6,411.8	6,788.3	7,191.5
	Interest Income	Min	31.7	16.7	20.9	22.7	26.6
		Mean	507,038	439,516	460,686	472,879	499,882
		Max	1,789,039	1,740,749	1,629,602	1,896,929	2,048,363
		S.D	498,558	458,843	487,366	530,046	551,876
Inputs	*Total Deposits*	Min	58,302	88,858	230	63,782	108,898
		Mean	4,061,845	4,228,310	5,062,026	4,953,697	5,237,108
		Max	14,546.3	17,012.4	19,591.8	19,609.2	20,411,793
		S.D	4,175,951	4,792,671	6,003,002	5,786,749	5,749,857
	Interest Expense	Min	15,366	9,859	14,200	15,680	16,598
		Mean	252,715	210,975	221,332	230,517	251,600
		Max	801,916	743,969	751,450	900,256	958,992
		S.D	242,089	206,6831	225,144	243,957	249,853
	N		**16**	**20**	**20**	**18**	**16**

Linear programming

In order to calculate these indices it is necessary to solve several sets of linear programming problems. We assume that there are *N* financial institutions and that each varying amounts of *K* different inputs to produce *M* outputs. The *i* th financial institutions is therefore represented by the vectors x_i y_i and the *K* x *N* input matrix *X* and the *M* x *N* output matrix *Y* represent the data of all financial institutions in the sample. The purpose is to construct a non-parametric envelopment frontier over the data points such that all observed points lie on or below the production frontier. The calculations exploit the fact that the input distance functions, *D*, used to construct the Malmquist index are the reciprocals of Farrell (1957) output orientation technical efficiency measures. The equations 5 and 6 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 equations 7 and 8 occur where the reference technology is constructed from data in one period, whereas the observation to be evaluated is from another period. Assuming a constant returns to scale, the following output oriented linear programming are used:

$$D_j^{\,t}[y^t, x^t]^{-1} = \max_{\theta,\lambda} \theta \qquad (5)$$

$$s.t. \; -y_{jt} + Y_t\lambda \geq 0 \qquad \theta x_{jt} - X_t\lambda \geq 0 \qquad \lambda \geq 0$$

$$D_j^{\,t+1}[y^{t+1}, x^{t+1}]^{-1} = \max_{\theta,\lambda} \theta \qquad (6)$$

$$s.t. \; -y_{jt+1} + Y_{t+1}\lambda \geq 0 \qquad \theta x_{jt+1} - X_{t+1}\lambda \geq 0 \qquad \lambda \geq 0$$

$$D_j^{\,t+1}[y^t, x^t]^{-1} = \max_{\theta,\lambda} \theta \qquad (7)$$

$$s.t. \; -y_{jt} + Y_{t+1}\lambda \geq 0 \qquad \theta x_{jt} - X_{t+1}\lambda \geq 0 \qquad \lambda \geq 0$$

$$D^t{}_j[y^{t+1}, x^{t+1}]^{-1} = \max_{\theta,\lambda} \theta \qquad (8)$$

$$s.t. \; -y_{jt+1} + Y_t\lambda \geq 0 \qquad \theta x_{jt+1} - X_t\lambda \geq 0 \qquad \lambda \geq 0$$

This approach can be further extended by decomposing the constant returns to scale technical efficiency change into scale efficiency and pure technical efficiency components. This involves calculating further linear programs where the convexity constraint N_i $\lambda = 1$ is introduced to equations 5 to 8. It is apparent that equation (6) and (7) give the Farrell efficiency scores and the programming problems are the dual form of the Charnes *et al.* (1978) data envelopment model. Solutions to these programming models give us the efficiency scores of the *j* th firm in periods *t* and *t+1*. By solving the equations with the same data under a constant returns to scale and variable returns to scale, measures of overall technical efficiency, *TE*, and pure technical efficiency, *PTE*, are obtained. Hence, dividing the overall technical efficiency, *TE*, by pure technical efficiency yields a measure of scale efficiency, *SE*.

By combining these models and the Fare *et al.* (1994) approach, it is thus possible to provide four efficiency indices for each firm and a measure of technical progress over time. These are (i) Technical Efficiency Change (TE), (ii) Technological Change (TC), (iii) Pure Technical Efficiency Change (PTE), (iv) Scale Efficiency Change and (v) Total Factor Productivity Change (M). *M* indicates the degree of productivity change; $M > 1$ means that period (t+1) productivity is greater than period *t* productivity, whilst $M < 1$ means productivity decline and $M = 1$ corresponds to stagnation. An assessment can be made of the sources of productivity gains or losses by comparing the values of *TE* and *TC*. If $TE > TC$, then productivity gains are largely the result of improvements in efficiency. Whereas if $TE < TC$, productivity gains are primarily the result of technological progress.