Measuring the efficiency of banking systems: A relational two-stage window DEA approach

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Abstract

This study examines the efficiency of banking systems in seventeen OECD countries over the period 1999-2009. For the purpose of our analysis we introduce a window-based version of two relational two-stage DEA models. Furthermore, we apply different versions of the additive and the multiplicative decomposition approaches in order to capture the trends of the efficiencies over the examined period. The robust version of the proposed models enables us to treat deposits as an intermediate variable and therefore be able to link the "value added activity" stage with the "profitability" stage over time. Our findings reveal similarities among the results of the two models. Finally, the estimated efficiencies appear to have minor fluctuations indicating a stability of the examined banking systems over time.

Keywords: Relational two-stage DEA; Window analysis; Banking systems.

Introduction

An efficiency measure for banking industry should be multi-dimensional since banks are complex organizations employing multiple inputs to produce multiple outputs. Data Envelopment Analysis (DEA) is a mathematical programming approach which has the ability to incorporate multiple inputs and outputs and provide measures of relative efficiency. Berger and Humphrey [1] provide an extensive literature of 130 studies in banking efficiency measurement, half of which used DEA approach.

Although a lot of studies investigate the efficiency of banking institutions, only a small fraction of these deal with the efficiency of banking systems across countries. In a novel study, Berg et al. [2] used DEA to evaluate the efficiency of the banking systems in Norway, Finland and Sweden. Fecher and Pestieau [3] measured the cross-country banking efficiency in eleven OECD countries. Allen and Rai [4] and Pastor et al. [5] used DEA to assess the banking efficiency of fifteen and eight developed countries respectively. The vast majority of the existing studies examine the European banking industry [6-11].

One controversial discussion about banking efficiency is the specification of deposits; whether they are inputs or outputs. Berger and Humphrey [12] presented three approaches about banking efficiency. The asset or intermediation approach considers banks as intermediaries in the financial process which use liabilities (e.g. deposits) in order to produce earning assets (e.g. loans and securities). The value added or production approach considers all financial products with a value added for the bank as outputs (e.g. deposits, loans). The user cost approach considers a financial product as an input or output according to its contribution into bank revenue. If the cost of the financial product (e.g. deposits) is lower that the opportunity cost then it is considered as output while if this is not the case it is considered as input. Berger and

Humphrey [12] argued that deposits have both input and output characteristics. An interesting alternative is to consider loanable funds (like deposits) as an intermediate variable in a two-stage process; in the first stage the bank consumes inputs to produce deposits and in the second stage the bank uses deposits to produce earning assets [13-15]. This approach insures that the dual role of deposits will be kept intact.

In this study we propose a relational two-stage window DEA approach in order to measure the banking systems in 17 OECD countries between 1999 and 2009. To the best of our knowledge this is the first time that a two-stage DEA model is applied at cross-country banking systems. We adopt the multiplicative two-stage DEA model of Kao and Hwang [16] and the additive two-stage DEA model of Chen et al. [17] and we perform window analysis. Such an analysis enables us to handle panel data in a two-stage DEA framework and provide us with robust efficiency measures. As far as we know this is the first time the multiplicative model of Kao and Hwang [16] is extended to window analysis. The additive model of Chen et al. [17] has been extended to window analysis by Ho et al. [18]. Finally and in contrast to the pre-mentioned study we present the mathematical formulation of both models in a window based framework.

The paper is structured as follows: Section 2 reviews current relative studies about two-stage DEA and banking industry. Section 3 provides the specification of the models and the proposed mathematical formulations while Section 4 presents and discusses the empirical application. The last section concludes the paper.

2. Literature Review

When decision making units (DMUs) in a data set have complex structures, we use DEA models which consist of multiple stages which are linked with intermediate variables. These intermediates variables are considered as inputs in the one stage and outputs in another stage. The general concept of two-stage DEA models is based on the seminal study of Färe and Grosskopf [19] who were the first to study the internal procedures of the “black box”. Wang et al. [20] and Seiford and Zhu [21] were the first to present a pure two-stage DEA model where all the outputs of the first stage are the only inputs in the second stage.

We can classify these models into four categories. First, independent two-stage DEA models which evaluate the efficiency of each stage separately, without considering the interaction and possible conflicts between the two stages [20, 21]. Second, the connected two-stage DEA models which consider the interactions between the stages and ensure that in order for a DMU to be overall efficient both of the stages need to be fully efficient [19, 22]. The third category is relational two-stage DEA models which assume a mathematical relationship (additive or multiplicative) between the overall and the individual efficiencies [16, 17]. The last category is about game theoretic two-stage DEA models [23, 24]. For a detailed review of two-stage DEA models see Cook et al. [25] and Halkos et al. [26].

Two-stage DEA studies are becoming very popular especially for analyzing banks’ efficiency levels. Wang et al. [20] constructed a model which measures the information technology-related activity in the first stage and the loan processing system in the second stage of 22 banks. A lot of studies have also used the same data set however with different modeling formulations [22, 24]. Seiford and Zhu [21] evaluated the profitability and marketability of 55 US commercial banks. The same model has also been examined by others using various formulations [24, 27]. Alternative formulations and approaches have been used in order to study banking efficiency in various real life case studies. Fukuyama and Weber [14] constructed a slacks-based network DEA model to measure the value-added activity in the first stage and the profitability in the second stage of Japanese banks. Fukuyama and Matousek [15] proposed a static network DEA model in order to examine the value-added activity and the profitability of 25 Turkish commercial banks. Akther et al. [28] investigated 19 private commercial banks and 2 government-owned in Bangladesh. Their model examined the value-added activity in the first stage and the profit generation in the second stage.

3. The model

3.1 The multiplicative two-stage DEA model

In this section, we present the multiplicative model of Kao and Hwang [16] which evaluates the overall and the individual efficiencies as follows:

$$E_0 = \frac{\sum_{r=1}^{s} u_r^* \cdot y_{r0}}{\sum_{i=1}^{m} v_i^* \cdot x_{i0}} \leq 1,\ E_0^1 = \frac{\sum_{d=1}^{D} w_d^* \cdot z_{d0}}{\sum_{i=1}^{m} v_i^* \cdot x_{i0}} \leq 1 \text{ and } E_0^2 = \frac{\sum_{r=1}^{s} u_r^* \cdot y_{r0}}{\sum_{d=1}^{D} w_d^* \cdot z_{d0}} \leq 1 \tag{1}$$

where u_r^*, v_i^* and w_p^* are the optimal weights. Then, the overall efficiency is evaluated as the product of the two individual efficiencies: $E_0 = E_0^1 \times E_0^2$ and constraints (1) are used in the model in order to incorporate the interaction between the two stages. Furthermore, the weights of intermediate measures are considered the same regardless they are outputs in stage 1 or inputs in stage 2. This key assumption connects the two stages and allows the conversion of the program into a linear one.

$$
\begin{aligned}
&E_0 = max \sum_{r=1}^{s} \gamma_r \cdot y_{rj_0} \\
&s.t. \quad \sum_{i=1}^{m} \omega_i \cdot x_{ij_0} = 1 \\
&\sum_{r=1}^{s} \gamma_r \cdot y_{rj} - \sum_{i=1}^{m} \omega_i \cdot x_{ij} \leq 0, \\
&\sum_{d=1}^{D} \mu_d \cdot z_{dj} - \sum_{i=1}^{m} \omega_i \cdot x_{ij} \leq 0, \\
&\sum_{r=1}^{s} \gamma_r \cdot y_{rj} - \sum_{d=1}^{D} \mu_d \cdot z_{dj} \leq 0, \\
&\gamma_r, \omega_i, \mu_d \geq \varepsilon;\ i = 1,2,\ldots,m;\ r = 1,2,\ldots,s;\ d = 1,2,\ldots,D;\ j = 1,2,\ldots,n
\end{aligned}
\tag{2}
$$

Model (2) may not yield unique optimal weights, so the decomposition of the overall efficiency E_0 may not be unique either. Kao and Hwang [16] give pre-emptive priority to one stage while maintaining the overall efficiency at E_0 as calculated in (2). This can be done by finding a set of multipliers which yield the largest efficiency for the stage with the pre-emptive priority. The other individual efficiency E_0^2 is calculated as $E_0 = E_0^1 \times E_0^2 \Rightarrow E_0^2 = \frac{E_0}{E_0^1}$. Here, we choose to give priority to the first stage[1].

$$
\begin{aligned}
&E_0^1 = max \sum_{d=1}^{D} \mu_d \cdot z_{dj_0} \\
&s.t. \quad \sum_{i=1}^{m} \omega_i \cdot x_{ij_0} = 1 \\
&\sum_{r=1}^{s} \gamma_r \cdot y_{rj_0} - E_0 \cdot \sum_{i=1}^{m} \omega_i \cdot x_{ij_0} = 0 \\
&\sum_{r=1}^{s} \gamma_r \cdot y_{rj} - \sum_{i=1}^{m} \omega_i \cdot x_{ij} \leq 0 \\
&\sum_{d=1}^{D} \mu_d \cdot z_{dj} - \sum_{i=1}^{m} \omega_i \cdot x_{ij} \leq 0 \\
&\sum_{r=1}^{s} \gamma_r \cdot y_{rj} - \sum_{d=1}^{D} \mu_d \cdot z_{dj} \leq 0 \\
&\gamma_r, \omega_i, \mu_d \geq \varepsilon;\ i = 1,2,\ldots,m;\ r = 1,2,\ldots,s;\ d = 1,2,\ldots,D;\ j = 1,2,\ldots,n
\end{aligned}
\tag{3}
$$

[1] We will explain later our choice about the priority of the first stage in our empirical application.

3.2 The additive two-stage DEA model

Next, we present the additive efficiency decomposition approach in a two-stage DEA model [17]. The overall efficiency E_0 is evaluated as follows:

$$E_0 = \xi_1 \cdot \frac{\sum_{d=1}^{D} w_d \cdot z_{dj_0}}{\sum_{i=1}^{m} v_i \cdot x_{ij_0}} + \xi_2 \cdot \frac{\sum_{r=1}^{s} u_r \cdot y_{rj_0}}{\sum_{d=1}^{D} w_d \cdot z_{dj_0}} \tag{4}$$

where ξ_1 and ξ_2 represent the relative contribution of each stage to the whole process. Chen et al. [17] chose not to specify these weights in an arbitrary way instead they proposed the size of each stage as a measure for its contribution to the whole process. The authors suggested total inputs of each stage as a proxy for their size. Following this reasoning the overall size of the DMU is defined as $\sum_{i=1}^{m} v_i \cdot x_{ij_0} + \sum_{d=1}^{D} w_d \cdot z_{dj_0}$ which is the sum of the first stage size $\sum_{i=1}^{m} v_i \cdot x_{ij_0}$ and the second stage size $\sum_{d=1}^{D} w_d \cdot z_{dj_0}$. Therefore, the relative contribution of each stage to the whole process is defined as:

$$\xi_1 = \frac{\sum_{i=1}^{m} v_i \cdot x_{ij_0}}{\sum_{i=1}^{m} v_i \cdot x_{ij_0} + \sum_{d=1}^{D} w_d \cdot z_{dj_0}} \quad \text{and} \quad \xi_2 = \frac{\sum_{d=1}^{D} w_d \cdot z_{dj0}}{\sum_{i=1}^{m} v_i \cdot x_{i0} + \sum_{d=1}^{D} w_d \cdot z_{d0}} \tag{5}$$

where $\xi_1 + \xi_2 = 1$. In addition, ξ_1 and ξ_2 follow the denominator rule and according to which we can achieve consistency when we aggregate ratio-type performance measures if we define the weights in terms of the denominator [29].

Chen et al. [17] incorporated ξ_1 and ξ_2 in (4) and constructed the following linear programming model using Charnes-Cooper transformation.

$$
\begin{aligned}
&E_0 = max \sum_{d=1}^{D} \mu_d \cdot z_{dj_0} + \sum_{r=1}^{s} \gamma_r \cdot y_{rj_0} \\
&s.t. \quad \sum_{i=1}^{m} \omega_i \cdot x_{ij_0} + \sum_{d=1}^{D} \mu_d \cdot z_{dj_0} = 1, \\
&\sum_{d=1}^{D} \mu_d \cdot z_{dj} - \sum_{i=1}^{m} \omega_i \cdot x_{ij} \leq 0, \\
&\sum_{r=1}^{s} \gamma_r \cdot y_{rj} - \sum_{d=1}^{D} \mu_d \cdot z_{dj} \leq 0, \\
&\gamma_r, \omega_i, \mu_d \geq \varepsilon;\ i = 1,2,\ldots,m;\ r = 1,2,\ldots,s;\ d = 1,2,\ldots,D;\ j = 1,2,\ldots,n
\end{aligned} \tag{6}
$$

The optimal multipliers $\gamma_r^*, \omega_i^*, \mu_d^*$ in model (6) may not be unique and as a result there might be more than one optimal solution. Chen et al. [17] deal with this problem by following the approach of Kao and Hwang [16] as presented above. Again, we choose to give priority to the first stage.

$$
\begin{aligned}
&E_0^1 = max \sum_{d=1}^{D} \mu_d \cdot z_{dj_0} \\
&s.t. \quad \sum_{i=1}^{m} \omega_i \cdot x_{ij_0} = 1, \\
&(1 - E_0) \cdot \sum_{d=1}^{D} \mu_d \cdot z_{dj_0} + \sum_{r=1}^{s} \gamma_r \cdot y_{rj_0} = E_0, \\
&\sum_{d=1}^{D} \mu_d \cdot z_{dj} - \sum_{i=1}^{m} \omega_i \cdot x_{ij} \leq 0, \\
&\sum_{r=1}^{s} \gamma_r \cdot y_{rj} - \sum_{d=1}^{D} \mu_d \cdot z_{dj} \leq 0, \\
&\gamma_r, \omega_i, \mu_d \geq \varepsilon;\ i = 1,2,\ldots,m;\ r = 1,2,\ldots,s;\ d = 1,2,\ldots,D;\ j = 1,2,\ldots,n
\end{aligned} \tag{7}
$$

Then, the second stage efficiency E_0^2 is calculated as:

$$
E_0^2 = \frac{E_0 - \xi_1^* \cdot E_0^1}{\xi_2^*} \tag{8}
$$

where ξ_1^* and ξ_2^* are the optimal weights from model (6) by the way of (5).

3.3 Window analysis in relational two-stage DEA models

Charnes and Cooper [30] introduced DEA window analysis which is based on the principle of moving averages in order to measure efficiency in cross-sectional data over time. Asmild et al. [31] suggest that by comparing the performance of a DMU against its own performance over other periods and against the performance of the other DMUs provides a useful tool to detect efficiency trends over time. As a moving average procedure it requires a sliding window to be defined which is the number of periods included in the analysis every time. According to Asmild et al. [31] there are no technical changes within each of the windows because all DMUs in each window are measured against each other. In addition, the authors recommend a narrow window width in order to yield credible results.

For this study we use 17 countries $(n=17)$ for the time period of 1999–2009 $(T=11)$. Following Asmild et al. [31] we have chosen a 3-year window for our analysis $(w=3)$. Specifically, the first window in our analysis contains the years 1999, 2000 and 2001 therefore the number of DMUs in our model is 51 $(n \times w = 17 \times 3)$. Then the second window moves one year forward including 2002 and appending 1999 and the procedure moves on until the last window. The overall procedure includes 9 windows and 459 different DMUs.

Adopting the notation of Asmild et al. [31] and after modifying it for the needs of a two-stage analysis, we consider n DMUs $(j=1,...,n)$ for T periods $(t=1,...,T)$ and $x_t^j = \left(x_{1t}^j, x_{2t}^j, \dots, x_{mt}^j\right)'$, $z_t^j = \left(z_{1t}^j, z_{2t}^j, \dots, z_{Dt}^j\right)'$ and $y_t^j = \left(y_{1t}^j, y_{2t}^j, \dots, y_{st}^j\right)'$ are the *i*-dimensional input vector $(i=1,...,m)$, the *d*-dimensional intermediate variable vector $(d=1,...,D)$ and the *r*-dimensional output vector $(r=1,...,s)$ respectively of the *j*th DMU $(j=1,...,n)$ at time t.

Then a window k_w with $k \times w$ observations is denoted starting at time k, $1 \le k \le T$ width w, $1 \le w \le T-k$. The matrix of inputs is given as:

$$X_{k_w} = \left(x_k^1, x_k^2, \ldots, x_k^n, x_{k+1}^1, x_{k+1}^2, \ldots, x_{k+1}^n, \ldots, x_{k+w}^1, x_{k+w}^2, \ldots, x_{k+w}^n\right) \text{ ,}$$

the matrix of intermediate variables is given as:

$$Z_{k_w} = \left(z_k^1, z_k^2, \ldots, z_k^n, z_{k+1}^1, z_{k+1}^2, \ldots, z_{k+1}^n, \ldots, z_{k+w}^1, z_{k+w}^2, \ldots, z_{k+w}^n\right) \text{ ,}$$

and the matrix of outputs is given as:

$$Y_{k_w} = \left(y_k^1, y_k^2, \ldots, y_k^n, y_{k+1}^1, y_{k+1}^2, \ldots, y_{k+1}^n, \ldots, y_{k+w}^1, y_{k+w}^2, \ldots, y_{k+w}^n\right) \text{ .}$$

The multiplicative two-stage window DEA model for the *jth* DMU at time t will be the following:

$$\begin{aligned}
& E_{\mathrm{k_w}t} = max\ \gamma \cdot y_t' \\
& s.t. \quad \omega \cdot x_t' = 1, \\
& \gamma \cdot Y_{k_w} - \omega \cdot X_{k_w} \leq 0, \\
& \mu \cdot Z_{k_w} - \omega \cdot X_{k_w} \leq 0, \\
& \gamma \cdot Y_{k_w} - \mu \cdot Z_{k_w} \leq 0, \\
& \gamma_r, \omega_i, \mu_d \geq \varepsilon; i = 1,2,\ldots,m; r = 1,2,\ldots,s; d = 1,2,\ldots,D; \ j = 1,2,\ldots,n \times w
\end{aligned} \tag{9}$$

the first stage efficiency of the multiplicative window model which we have chosen to give pre-emptive priority, is as follows:

$$\begin{aligned}
& E_{\mathrm{k_w}t}^1 = max\ \mu \cdot z_t' \\
& s.t. \quad \omega \cdot x_t' = 1, \\
& \gamma \cdot y_t' - E_{\mathrm{k_w}} \cdot \omega \cdot x_t' = 0, \\
& \gamma \cdot Y_{k_w} - \omega \cdot X_{k_w} \leq 0, \\
& \mu \cdot Z_{k_w} - \omega \cdot X_{k_w} \leq 0, \\
& \gamma \cdot Y_{k_w} - \mu \cdot Z_{k_w} \leq 0, \\
& \gamma_r, \omega_i, \mu_d \geq \varepsilon; i = 1,2,\ldots,m; r = 1,2,\ldots,s; d = 1,2,\ldots,D; \ j = 1,2,\ldots,n \times w
\end{aligned} \tag{10}$$

and the second stage efficiency is calculated as:

$$E_{\mathrm{k_w t}}^2 = \frac{E_{\mathrm{k_w t}}}{E_{\mathrm{k_w t}}^1} \tag{11}$$

Similarly, the additive two-stage window DEA model for the *jth* DMU at time t will be the following:

$$
\begin{aligned}
&E_{k_w t} = max\ \mu \cdot z'_{dj_0} + \gamma \cdot y'_{rj_0} \\
&s.t. \quad \omega \cdot x'_{ij_0} + \mu \cdot z'_{dj_0} = 1, \\
&\mu \cdot Z_{k_w} - \omega \cdot X_{k_w} \le 0, \\
&\gamma \cdot Y_{k_w} - \mu \cdot Z_{k_w} \le 0, \\
&\gamma_r, \omega_i, \mu_d \ge \varepsilon;\ i = 1,2,\ldots,m;\ r = 1,2,\ldots,s;\ d = 1,2,\ldots,D;\ j = 1,2,\ldots,n \times w
\end{aligned} \tag{12}
$$

the first stage efficiency of the additive window model is as follows:

$$
\begin{aligned}
&E^1_{k_w t} = max\ \mu \cdot z'_{dj_0} \\
&s.t. \quad \omega \cdot x'_{ij_0} = 1, \\
&(1 - E_{k_w}) \cdot \mu \cdot Z_{k_w} + \gamma \cdot Y_{k_w} = E_{k_w}, \\
&\mu \cdot Z_{k_w} - \omega \cdot X_{k_w} \le 0, \\
&\gamma \cdot Y_{k_w} - \mu \cdot Z_{k_w} \le 0, \\
&\gamma_r, \omega_i, \mu_d \ge \varepsilon;\ i = 1,2,\ldots,m;\ r = 1,2,\ldots,s;\ d = 1,2,\ldots,D;\ j = 1,2,\ldots,n \times w
\end{aligned} \qquad (13).
$$

and then the second stage efficiency is:

$$
E^2_{k_w t} = \frac{E_{k_w t} - \xi_1^* \cdot E^1_{k_w t}}{\xi_2^*} \tag{14}
$$

where ξ_1^* and ξ_2^* are the optimal weights from model (12) computed in a similar manner as in (5).

4. Empirical application

We now demonstrate our relational window two-stage DEA models by estimating the efficiency of 17 OECD countries for the period 1999-2009 using annual data from OECD[2]. As we described in the previous section we treat deposits as intermediate variables in a two-stage process [13-15]. This approach perfectly matches the view of Sealey and Lindley [32] about banking process where banks are multistage entities which use labor, capital and other inputs to obtain loanable funds

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[22]The data have been obtained from the OECD database on 'Bank Profitability' and are available only for the period 1999-2009. The data are available from: http://stats.oecd.org/. Due to space restrictions we avoided to present a table with descriptive statistics of the variables used. However, this is available alongside with the data upon request.

which then utilize to produce earning assets.

We also adopt a similar specification for inputs-outputs with Holod and Lewis [13] and Fukuyama and Matousek [15]. In the first stage we measure the “value added activity” and in the second stage we measure the “profitability” of the banking system. Specifically, in our model we use two inputs: total number of employees and total fixed assets. Furthermore, we use two intermediate variables: interbank deposits and customer deposits. Lastly, we use two outputs: loans and securities. All variables except labor are measured in millions of dollars. We chose the input-oriented version of the models as presented in (9)-(14) and also we chose to give priority to the first stage because banks have greater control over their inputs compared to their outputs.

In Tables 1 and 2 we examine the efficiencies over time by applying window analysis at the multiplicative [16] and additive [17] two-stage DEA models respectively for the case of USA[3]. The results can be read in two ways, by rows and by columns. The rows indicate the trend as well as the behavior across the same data set (the same window), while the column indicate the stability of the efficiency for a specific year across different data sets (different windows). Considering the above, the efficiency scores seem to be stable across different data sets and also appear to slightly decline over the years.

Tables 3 and 4 provide the average values of each year for the overall efficiencies, the “value added activity” efficiencies and the “profitability” efficiencies. The interpretation of the results for all countries across eleven years is difficult, so in order to facilitate the comprehension of the results we provide the average efficiency over time (1999-2009) for each country along with the average annual growth in Tables 5 and 6.

[3] Tables 1 and 2 are provided for the case of USA as an illustrative example. The results for all countries are available upon request.

Table 1: A three-year window analysis of overall, first stage and second stage efficiencies of the multiplicative model for the case of USA.

Overall efficiencies	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
W1	0.310	0.311	0.288								
W2		0.295	0.269	0.287							
W3			0.260	0.277	0.277						
W4				0.282	0.283	0.260					
W5					0.273	0.255	0.249				
W6						0.250	0.248	0.240			
W7							0.243	0.235	0.229		
W8								0.236	0.230	0.226	
W9									0.247	0.246	0.262
Averages	0.310	0.303	0.272	0.282	0.278	0.255	0.247	0.237	0.235	0.236	0.262
1st stage efficiencies											
W1	0.417	0.417	0.436								
W2		0.404	0.416	0.431							
W3			0.378	0.392	0.391						
W4				0.387	0.335	0.317					
W5					0.285	0.275	0.279				
W6						0.394	0.399	0.384			
W7							0.396	0.382	0.368		
W8								0.384	0.369	0.384	
W9									0.327	0.334	0.385
Averages	0.417	0.411	0.410	0.404	0.337	0.328	0.358	0.383	0.355	0.359	0.385
2nd stage efficiencies											
W1	0.745	0.745	0.661								
W2		0.731	0.647	0.665							
W3			0.686	0.707	0.710						
W4				0.730	0.845	0.822					
W5					0.958	0.928	0.893				
W6						0.635	0.622	0.624			
W7							0.613	0.614	0.624		
W8								0.614	0.624	0.589	
W9									0.754	0.736	0.680
Averages	0.745	0.738	0.665	0.701	0.837	0.795	0.709	0.617	0.667	0.663	0.680

Table 2: A three-year window analysis of overall, first stage and second stage efficiencies of the additive model for the case of USA.

Overall efficiencies	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
W1	0.514	0.514	0.504								
W2		0.502	0.486	0.502							
W3			0.471	0.487	0.486						
W4				0.487	0.487	0.462					
W5					0.472	0.452	0.453				
W6						0.465	0.466	0.454			
W7							0.459	0.448	0.438		
W8								0.448	0.438	0.441	
W9									0.452	0.454	0.481
Averages	0.514	0.508	0.487	0.492	0.482	0.460	0.459	0.450	0.443	0.448	0.481
1st stage efficiencies											
W1	0.423	0.417	0.436								
W2		0.415	0.426	0.442							
W3			0.406	0.421	0.419						
W4				0.419	0.418	0.390					
W5					0.401	0.381	0.385				
W6						0.406	0.411	0.395			
W7							0.403	0.389	0.374		
W8								0.386	0.371	0.386	
W9									0.401	0.394	0.433
Averages	0.423	0.416	0.423	0.427	0.413	0.392	0.400	0.390	0.382	0.390	0.433
2nd stage efficiencies											
W1	0.728	0.745	0.661								
W2		0.711	0.626	0.638							
W3			0.633	0.646	0.648						
W4				0.650	0.652	0.644					
W5					0.649	0.640	0.629				
W6						0.610	0.600	0.601			
W7							0.599	0.601	0.610		
W8								0.609	0.618	0.584	
W9									0.578	0.606	0.592
Averages	0.728	0.728	0.640	0.645	0.650	0.632	0.609	0.604	0.602	0.595	0.592

Table 3: Overall, first and second stage efficiencies (average values obtained by two-stage multiplicative DEA window analysis)

Overall efficiency																	
	Austria	**Belgium**	**Denmark**	**Estonia**	**Finland**	**France**	**Germany**	**Italy**	**Korea, Rep**	**Netherlands**	**Norway**	**Poland**	**Slovak Republic**	**Spain**	**Sweden**	**Switzerland**	**USA**
1999	0.836	0.939	0.442	0.294	0.418	0.515	0.640	0.279	0.382	0.845	0.789	0.297	0.259	0.468	0.364	0.684	0.310
2000	0.863	0.899	0.443	0.370	0.458	0.514	0.649	0.283	0.442	0.852	0.801	0.248	0.222	0.446	0.407	0.642	0.303
2001	0.775	0.879	0.496	0.504	0.455	0.483	0.713	0.267	0.448	0.826	0.829	0.198	0.187	0.467	0.405	0.642	0.272
2002	0.801	0.742	0.432	0.547	0.477	0.454	0.801	0.239	0.446	0.865	0.735	0.191	0.192	0.501	0.375	0.563	0.282
2003	0.724	0.670	0.574	0.624	0.243	0.433	0.821	0.207	0.406	0.906	0.612	0.237	0.545	0.544	0.349	0.538	0.278
2004	0.812	0.597	0.444	0.674	0.241	0.399	0.772	0.187	0.463	0.926	0.771	0.165	0.606	0.563	0.372	0.503	0.255
2005	0.772	0.583	0.308	0.671	0.247	0.409	0.808	0.178	0.549	0.856	0.848	0.176	0.541	0.500	0.411	0.512	0.247
2006	0.773	0.550	0.505	0.722	0.251	0.393	0.788	0.178	0.556	1.000	0.850	0.171	0.371	0.506	0.409	0.486	0.237
2007	0.787	0.559	0.461	0.647	0.266	0.415	0.769	0.183	0.527	0.986	0.770	0.155	0.466	0.520	0.444	0.510	0.235
2008	0.660	0.561	0.359	0.799	0.261	0.394	0.631	0.188	0.407	0.664	0.606	0.210	0.423	0.435	0.387	0.358	0.236
2009	0.666	0.570	0.440	0.740	0.212	0.395	0.711	0.194	0.522	0.655	0.871	0.278	0.528	0.536	0.455	0.661	0.262
First stage efficiency																	
	Austria	**Belgium**	**Denmark**	**Estonia**	**Finland**	**France**	**Germany**	**Italy**	**Korea, Rep**	**Netherlands**	**Norway**	**Poland**	**Slovak Republic**	**Spain**	**Sweden**	**Switzerland**	**USA**
1999	1.000	0.960	0.556	0.479	0.550	0.803	0.792	0.291	0.601	0.962	0.944	0.492	0.598	0.755	0.501	1.000	0.417
2000	0.994	0.899	0.501	0.650	0.591	0.670	0.768	0.283	0.764	0.971	0.924	0.404	0.513	0.717	0.563	0.898	0.411
2001	0.942	0.887	0.509	0.867	0.567	0.623	0.847	0.267	0.781	0.955	0.963	0.351	0.307	0.754	0.564	0.900	0.410
2002	0.934	0.783	0.447	0.831	0.606	0.599	0.931	0.241	0.783	0.967	0.869	0.285	0.248	0.782	0.528	0.803	0.404
2003	0.850	0.763	0.574	0.836	0.329	0.533	0.963	0.207	0.700	1.000	0.690	0.295	0.545	0.778	0.467	0.778	0.337
2004	0.913	0.770	0.462	0.851	0.312	0.490	0.940	0.190	0.707	1.000	0.894	0.243	0.863	0.779	0.475	0.738	0.328
2005	0.870	0.843	0.382	0.955	0.311	0.513	1.000	0.184	0.847	0.971	0.967	0.289	0.992	0.709	0.499	0.763	0.358
2006	0.862	0.796	0.557	0.978	0.327	0.458	0.993	0.186	0.879	1.000	0.998	0.308	0.669	0.788	0.496	0.678	0.383
2007	0.901	0.746	0.538	0.776	0.339	0.417	0.986	0.183	0.756	1.000	0.884	0.289	0.810	0.783	0.582	0.768	0.355
2008	0.814	0.708	0.385	0.928	0.349	0.447	0.849	0.233	0.447	0.936	0.740	0.346	0.942	0.650	0.436	0.620	0.359
2009	0.897	0.689	0.440	1.000	0.282	0.467	0.946	0.253	0.639	0.872	1.000	0.465	0.889	0.726	0.546	1.000	0.385
Second stage efficiency																	
	Austria	**Belgium**	**Denmark**	**Estonia**	**Finland**	**France**	**Germany**	**Italy**	**Korea, Rep**	**Netherlands**	**Norway**	**Poland**	**Slovak Republic**	**Spain**	**Sweden**	**Switzerland**	**USA**
1999	0.836	0.978	0.796	0.613	0.760	0.642	0.808	0.957	0.635	0.879	0.835	0.604	0.434	0.620	0.728	0.684	0.745
2000	0.868	1.000	0.885	0.569	0.775	0.777	0.845	1.000	0.578	0.878	0.866	0.616	0.434	0.621	0.723	0.717	0.738
2001	0.823	0.990	0.975	0.581	0.802	0.777	0.842	1.000	0.576	0.865	0.861	0.567	0.631	0.620	0.717	0.712	0.665
2002	0.858	0.945	0.964	0.665	0.788	0.759	0.861	0.992	0.571	0.895	0.845	0.681	0.775	0.642	0.713	0.703	0.701
2003	0.852	0.878	1.000	0.747	0.740	0.812	0.853	0.997	0.580	0.906	0.886	0.804	1.000	0.699	0.747	0.692	0.837
2004	0.889	0.772	0.961	0.791	0.771	0.817	0.821	0.985	0.657	0.926	0.863	0.691	0.701	0.722	0.782	0.678	0.795
2005	0.887	0.700	0.803	0.701	0.792	0.810	0.808	0.963	0.650	0.880	0.879	0.621	0.545	0.706	0.823	0.671	0.709
2006	0.897	0.711	0.908	0.738	0.768	0.891	0.793	0.955	0.633	1.000	0.852	0.554	0.555	0.642	0.825	0.716	0.617
2007	0.874	0.750	0.858	0.834	0.786	0.995	0.779	1.000	0.708	0.986	0.871	0.535	0.576	0.663	0.762	0.665	0.667
2008	0.817	0.792	0.934	0.861	0.748	0.881	0.744	0.808	0.920	0.709	0.819	0.607	0.450	0.669	0.887	0.578	0.663
2009	0.743	0.827	1.000	0.740	0.754	0.846	0.752	0.768	0.816	0.752	0.871	0.597	0.594	0.738	0.834	0.661	0.680

Table 4: Overall, first and second stage efficiencies (average values obtained by two-stage additive DEA window analysis).

Overall efficiency																	
	Austria	Belgium	Denmark	Estonia	Finland	France	Germany	Italy	Korea, Rep	Netherlands	Norway	Poland	Slovak Republic	Spain	Sweden	Switzerland	USA
1999	0.918	0.969	0.642	0.526	0.624	0.732	0.799	0.442	0.619	0.921	0.891	0.529	0.536	0.697	0.576	0.842	0.514
2000	0.931	0.947	0.629	0.618	0.660	0.722	0.801	0.441	0.685	0.925	0.896	0.468	0.488	0.677	0.621	0.811	0.508
2001	0.884	0.933	0.666	0.733	0.652	0.684	0.844	0.420	0.691	0.910	0.913	0.421	0.407	0.696	0.619	0.809	0.487
2002	0.897	0.849	0.605	0.748	0.674	0.658	0.897	0.385	0.685	0.931	0.858	0.388	0.392	0.721	0.587	0.752	0.492
2003	0.851	0.812	0.730	0.791	0.430	0.636	0.908	0.342	0.650	0.953	0.770	0.431	0.709	0.744	0.556	0.739	0.482
2004	0.901	0.771	0.620	0.820	0.422	0.609	0.882	0.317	0.691	0.963	0.879	0.347	0.786	0.754	0.589	0.713	0.460
2005	0.878	0.782	0.500	0.831	0.427	0.623	0.904	0.307	0.758	0.926	0.923	0.371	0.769	0.707	0.630	0.730	0.459
2006	0.878	0.771	0.682	0.859	0.436	0.616	0.894	0.307	0.766	1.000	0.925	0.371	0.624	0.724	0.635	0.718	0.450
2007	0.888	0.767	0.652	0.801	0.452	0.628	0.884	0.309	0.738	0.993	0.878	0.346	0.707	0.731	0.653	0.728	0.443
2008	0.816	0.746	0.537	0.895	0.453	0.620	0.801	0.350	0.636	0.828	0.773	0.413	0.708	0.657	0.598	0.606	0.448
2009	0.829	0.745	0.611	0.870	0.395	0.607	0.851	0.361	0.719	0.816	0.935	0.507	0.757	0.731	0.648	0.830	0.481
First stage efficiency																	
	Austria	**Belgium**	**Denmark**	**Estonia**	**Finland**	**France**	**Germany**	**Italy**	**Korea, Rep**	**Netherlands**	**Norway**	**Poland**	**Slovak Republic**	**Spain**	**Sweden**	**Switzerland**	**USA**
1999	1.000	0.960	0.556	0.492	0.550	0.810	0.792	0.294	0.626	0.962	0.944	0.492	0.598	0.755	0.501	1.000	0.423
2000	0.994	0.899	0.503	0.650	0.591	0.781	0.768	0.283	0.781	0.971	0.924	0.431	0.526	0.717	0.563	0.898	0.416
2001	0.942	0.887	0.511	0.888	0.567	0.672	0.847	0.267	0.807	0.955	0.963	0.393	0.380	0.760	0.566	0.900	0.423
2002	0.939	0.783	0.449	0.836	0.606	0.633	0.931	0.241	0.783	0.967	0.869	0.335	0.341	0.793	0.529	0.803	0.427
2003	0.850	0.763	0.574	0.845	0.329	0.573	0.963	0.207	0.700	1.000	0.690	0.372	0.618	0.785	0.467	0.778	0.413
2004	0.913	0.770	0.462	0.851	0.314	0.543	0.946	0.191	0.751	1.000	0.894	0.289	0.865	0.779	0.535	0.748	0.392
2005	0.870	0.930	0.387	0.955	0.318	0.572	1.000	0.186	0.884	0.971	0.967	0.323	0.992	0.709	0.602	0.815	0.400
2006	0.862	1.000	0.557	0.978	0.327	0.597	0.993	0.186	0.895	1.000	0.998	0.322	0.681	0.790	0.661	0.856	0.390
2007	0.901	1.000	0.555	0.776	0.339	0.621	0.986	0.183	0.854	1.000	0.884	0.294	0.846	0.793	0.611	0.816	0.382
2008	0.915	0.762	0.385	0.928	0.349	0.645	0.849	0.249	0.668	0.970	0.740	0.346	0.979	0.650	0.538	0.631	0.390
2009	0.957	0.689	0.440	1.000	0.303	0.605	0.946	0.263	0.854	0.913	1.000	0.465	0.988	0.726	0.547	1.000	0.433
Second stage efficiency																	
	Austria	**Belgium**	**Denmark**	**Estonia**	**Finland**	**France**	**Germany**	**Italy**	**Korea, Rep**	**Netherlands**	**Norway**	**Poland**	**Slovak Republic**	**Spain**	**Sweden**	**Switzerland**	**USA**
1999	0.836	0.978	0.796	0.594	0.760	0.636	0.808	0.942	0.607	0.879	0.835	0.604	0.434	0.620	0.728	0.684	0.728
2000	0.868	1.000	0.880	0.569	0.775	0.647	0.845	1.000	0.561	0.878	0.866	0.555	0.415	0.621	0.723	0.717	0.728
2001	0.823	0.990	0.970	0.562	0.802	0.702	0.842	0.996	0.553	0.865	0.861	0.494	0.478	0.612	0.714	0.712	0.640
2002	0.852	0.945	0.961	0.661	0.788	0.703	0.861	0.992	0.571	0.895	0.845	0.551	0.545	0.632	0.711	0.703	0.645
2003	0.852	0.878	1.000	0.736	0.740	0.747	0.853	0.997	0.580	0.906	0.886	0.592	0.859	0.693	0.747	0.692	0.650
2004	0.889	0.772	0.961	0.791	0.764	0.734	0.815	0.977	0.612	0.926	0.863	0.547	0.699	0.722	0.689	0.666	0.632
2005	0.887	0.622	0.792	0.701	0.770	0.711	0.808	0.950	0.617	0.880	0.879	0.521	0.545	0.706	0.677	0.626	0.609
2006	0.897	0.543	0.908	0.738	0.768	0.648	0.793	0.955	0.621	1.000	0.852	0.522	0.541	0.641	0.597	0.556	0.604
2007	0.874	0.534	0.829	0.834	0.786	0.639	0.779	1.000	0.603	0.986	0.871	0.524	0.543	0.653	0.722	0.622	0.602
2008	0.708	0.730	0.934	0.861	0.748	0.580	0.744	0.754	0.590	0.681	0.819	0.607	0.431	0.669	0.707	0.567	0.595
2009	0.696	0.827	1.000	0.740	0.698	0.611	0.752	0.735	0.561	0.710	0.871	0.597	0.523	0.738	0.833	0.661	0.592

Similarly in Table 6 we present the results of the window additive two-stage DEA model and we compare them with the results obtained from multiplicative model in Table 5. Following Chen et al. [17] we compare the rankings of the two models because direct comparisons of the efficiency scores among different models may not yield reliable results. We also compare the average annual growth rates. Considering the overall efficiencies in Table 6 the rankings appear to be quite similar with those in Table 5. As we found in the previous case, Netherlands (0.924), Austria (0.879), Germany (0.876) and Norway (0.860) achieve the highest scores, the same ten countries experience positive growth and the same seven countries experience negative growth. However, now Italy achieves the lowest efficiency score (0.362).

Furthermore, we use the Pearson correlation coefficient to test our findings about the similarities of the two rankings and the similarities of average annual growth rates. The results (0.983 and 0.978 respectively) confirm our findings. Similar deductions can be made for the "value added activity" efficiency scores. Exactly as we found in Table 5, the highest scores are achieved by Netherlands (0.973), Austria (0.922), Germany (0.911) and Norway (0.898), the lowest score is achieved by Italy (0.232), sixteen countries experience similar trend pattern in average annual growth with the exception of USA (from -0.5% in Table 5 to +0.3% in Table 6). Our findings are confirmed by the results of the Pearson correlation coefficient (0.985 and 0.988 for the rankings and the average annual growth respectively).

Considering the "profitability" efficiency scores we find significant similarities among Table 5 and 6 again. Exactly as in Table 5, we find Italy (0.936), Denmark (0.912), the Netherlands (0.873) and Norway (0.859) as the most efficient countries and Slovak Republic (0.547) as the least efficient. In addition, we observe similar trend pattern for average annual growth in thirteen countries, however four countries yield slightly opposite results, Switzerland (from -0.1% in Table 5 to 0% in Table 6), Finland (from 0% in Table 5 to -0.8% in Table 6), France (from 3.2 % in Table 5 to -0.2% in Table 6) and Korea Republic (from 3.2% in Table 5 to -0.7% in Table 6). Pearson correlation coefficient indicates significant similarities for rankings (0.958) and significant but not so high correlation for average annual growth rates (0.793).

Table 5: Average efficiencies (1999-2009), average annual growth rates (% change 1999-2009) and rankings of the multiplicative model.

	Overall efficiencies			1st stage efficiencies			2nd stage efficiencies		
	Average efficiency	Average annual growth	Ranking	Average efficiency	Average annual growth	Ranking	Average efficiency	Average annual growth	Ranking
Austria	0.770	-0.019	3	0.907	-0.009	3	0.849	-0.011	5
Belgium	0.686	-0.047	5	0.804	-0.031	7	0.849	-0.015	6
Denmark	0.446	0.035	10	0.487	-0.001	13	0.917	0.027	2
Estonia	0.599	0.106	6	0.832	0.089	5	0.713	0.024	11
Finland	0.321	-0.046	14	0.415	-0.048	14	0.771	0.000	10
France	0.437	-0.025	11	0.547	-0.050	11	0.819	0.032	7
Germany	0.737	0.015	4	0.911	0.021	2	0.810	-0.007	8
Italy	0.217	-0.034	16	0.229	-0.008	17	0.948	-0.019	1
Korea, Rep	0.468	0.042	9	0.719	0.032	9	0.666	0.032	15
Netherlands	0.853	-0.017	1	0.967	-0.009	1	0.880	-0.010	3
Norway	0.771	0.026	2	0.898	0.020	4	0.859	0.005	4
Poland	0.211	0.016	17	0.343	0.010	16	0.625	0.006	16
Slovak Republic	0.395	0.167	13	0.670	0.119	10	0.609	0.061	17
Spain	0.499	0.019	8	0.747	0.000	8	0.668	0.019	14
Sweden	0.398	0.027	12	0.514	0.018	12	0.777	0.016	9
Switzerland	0.554	0.027	7	0.813	0.018	6	0.680	-0.001	13
USA	0.265	-0.015	15	0.377	-0.005	15	0.711	-0.005	12

Table 6: Average efficiencies (1999-2009), average annual growth rates (% change 1999-2009) and rankings of the additive model.

	Overall efficiencies			1st stage efficiencies			2nd stage efficiencies		
	Average efficiency	Average annual growth	Ranking	Average efficiency	Average annual growth	Ranking	Average efficiency	Average annual growth	Ranking
Austria	0.879	-0.009	2	0.922	-0.003	2	0.835	-0.016	5
Belgium	0.827	-0.025	5	0.859	-0.026	5	0.802	-0.006	7
Denmark	0.625	0.009	12	0.489	-0.001	13	0.912	0.028	2
Estonia	0.772	0.055	6	0.836	0.086	7	0.708	0.027	10
Finland	0.511	-0.036	14	0.418	-0.042	14	0.764	-0.008	8
France	0.649	-0.018	10	0.641	-0.027	11	0.669	-0.002	11
Germany	0.860	0.007	4	0.911	0.021	3	0.809	-0.007	6
Italy	0.362	-0.018	17	0.232	-0.004	17	0.936	-0.021	1
Korea, Rep	0.694	0.018	9	0.782	0.042	8	0.589	-0.007	15
Netherlands	0.924	-0.010	1	0.973	-0.005	1	0.873	-0.014	3
Norway	0.876	0.009	3	0.898	0.020	4	0.859	0.005	4
Poland	0.418	0.004	16	0.369	0.008	16	0.556	0.002	16
Slovak Republic	0.626	0.062	11	0.710	0.096	10	0.547	0.042	17
Spain	0.713	0.006	8	0.751	0.000	9	0.664	0.019	12
Sweden	0.610	0.013	13	0.556	0.014	12	0.713	0.018	9
Switzerland	0.753	0.006	7	0.841	0.017	6	0.655	0.000	13
USA	0.475	-0.006	15	0.408	0.003	15	0.638	-0.020	14

5. Conclusions

In this paper we have examined the efficiency of the banking system for seventeen OECD countries for eleven years (1999-2009) under relational two-stage DEA framework where deposits have been treated as intermediate variable linking the "value added activity" and the "profitability" of the banking system. We have measured the overall and the stages' efficiencies over time by applying window analysis at the multiplicative [16] and the additive [17] decomposition approaches. Additionally, we have provided the mathematical formulation of the models. The results of the two models are quite similar which serves as an indication of the robustness of the results. The similarity among the results of the two models coincides with the findings of Chen et al. [17] which we verify for the case of multiple time periods. In addition, the results are relatively stable over time and any positive or negative change is in minor scale.

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