Dynamics of innovation and efficiency in banking system: An application of SFA and meta-frontier method

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١. Introduction

Recent developments of financial sector and involvement of today's world in financial activities, made this sector to be at the core of the economy. In this context, banking system as the main part of financial sector, facilitates the transmission of financial resources from savers to borrowers in an uncertain environment (Frame and White ٢٠١٤). Banking system helps to moderate the operational risk of business enterprises by providing different financing options and resources. At the same time, banks as intermediary units, transfer money surplus of individuals to most efficient units in economy by employing a risk management and credit evaluation systems.

Banking sector, same as other economic sectors, applies labor and capital as real resources cost, however, their involvement in many fundamental uncertainties which are associated with financial activities faced them with different types of operational risks. In one hand, they have to dedicate huge efforts and resources to diminish the risk of their activities. In other hand, they have to satisfy their costumers by introducing more reliable and faster mechanisms in order to alter the financial risk of depositors and borrowers.

As a result, banks always try to introduce some new products and services which reduce the aforementioned risks and expenditures. We consider all these improvements as financial innovation and in this paper we try to explain its dynamics in US banking system. According to Frame and white (٢٠٠٤), regulation, size of financial enterprises, cost and technological opportunities are factors which foster innovation in financial institutions. Likewise innovation in non-financial contexts, financial innovation occurs in both new products/services and in new production process. Frame and White (٢٠١٤) categorized all financial innovations that happened in last ٣٠ years into three parts: "new products/services", "new production process" and " new organizational forms". For instance, they defined mortgage loans as a "new product" which has experienced great changes over time. New payment methods such as automated teller machines (ATMs), debit cards and online banking are good examples of "new services" in financial sectors. Automated Clearing-House (ACH), Asset Securitization and Small Business Credit Scoring are introduced as "new production processes" and the emergence of internet-only banking is a well-known example of "new organizational form".

Improvements in financial activities have a substantial role and broad effects in an economy and studies in financial innovation and its trend during the time have attracted a lot of attention in economics. It is noted by Allen (٢٠١٢) that there are two views about financial innovation effects. In fact we need to consider the positive and negative influences of this kind of innovation together. He discussed, in one hand, financial crises in ٢٠٠٧ as a *dark side* of financial innovation. On the other hand, the improvement in financial products which finance business enterprises is mentioned as a positive effect of financial innovation. Considering both advantages and disadvantages, he concluded that the positive impacts of financial innovation are more than the negative parts. Thus, as Frame and White (٢٠١٤) emphasize, financial innovations are associated with trial-and-error, even though the success of each innovation is not an inherent characteristics of that innovation. Moreover, financial innovation of a bank, per se, is a discrete event while may have long standing effects on economy and also on its own performance.

First step toward investigating the dynamic of innovation in each industry and evaluating its effects on economy is to measure innovation. However, one of the most important problems in innovation arguments is how to identify and measure it. In industry sector, the available measurements to identify innovation activities are number of patents, R&D expenditure and share of R&D workers. Unfortunately these measurements for service sector, especially financial sector, are problematic and not readily available. In literature there are a few studies about measuring financial innovation. This study attempts to identify and measure innovation in banking system as the most important section of financial institutions. Following Bos et al. (٢٠٠٩), we measure technology gap ratios in banking by applying frontier analysis: "changes in the technology gap show the relative improvements in technology sets, which in turn are affected by innovations". This study will employ Stochastic Frontier Analysis (SFA) to estimate the annual cost frontier functions and calculate the efficiency scores to compare banks in each year. Since firms in each year are working under different environments and regulations, the annual efficiency scores would not be comparable. Thus, to find a global frontier function and efficiency scores, the most efficient cost function (or the best-practice cost function) for the whole period has to be estimated. This way, we can compare the performance of each unit to the best-practice cost function which shows the efficiency level of each firm. Following, the gap between the annual cost frontier functions and the best-practice cost function can be measured.

All the above procedures can be implemented by meta-frontier function introduced by Battese et al. (٢٠٠٤) which fulfills two objectives:

i) produces an efficiency measurement which is comparable for all firms working under different technologies, ii) estimates the technology gap ratios which indicate the relative distance of different annual frontiers to the meta-frontier function. As a result, estimated technology gap ratio (TGR) and its trend can be utilized as an indicator for innovation activities in banking sector.

This study consists of six sections. Current introduction makes section one followed by section two representing the theoretical background and reviewing the relevant studies. Third section consists of the methodology of the study followed by fourth section which explains the data source and its structure. Section five covers the empirical results and at the end, we come to conclusions.

٢. Theoretical background

One of the most important problems in innovation arguments is how to identify and measure innovation activities. This issue becomes more serious in financial sector where its outputs are fundamentally different comparing to other industries. Moreover, it is difficult to directly attach the performance of financial institutions to their innovation activities. In the literature there are a few studies that addressed measuring financial innovation and this paper is an attempt to highlight some ideas in measuring financial innovation in banking system.

Bos et al. (٢٠٠٩) introduced a method to measure the technology gap ratio in banking system. They discussed that changes of technology gap ratio can be interpreted as the relative developments in technology sets. Put differently, changing in technology gap can be considered as a proxy of innovation activities. Therefore estimating the technology sets which indicates the possible combination of inputs and outputs (such as production function, profit function and cost function) can be a basis for measuring technology gap ratio.

Stochastic Frontier Analysis is a parametric approach in the benchmarking models and its estimation procedure is mainly based on econometric method (Coelli, Rao et al. ٢٠٠٥). Aigner et al. (١٩٧٧) firstly developed SFA in production function and introduced the definition of disturbance term in frontier function. The disturbance term is equal to the sum of "symmetric normal" and "half-normal random" variables. In another study, Meeusen and Broeck (١٩٧٧) proposed a new definition for error term which is a combination of efficiency measure and noise error term. They chose Cobb-Douglas production function as their functional form.

Efficiency measures resulted from SFA approach enables us to compare the performances of several firms operating under the same technologies or regulations. In other words, all firms in this explanation have to be working in the common environment or at least very similar situations. This condition put a strong constraint on the SFA model in which we cannot compare companies in different countries, industries and even different years. Therefore, latter studies try to introduce new approaches putting this limitation aside.

The first attempt back to the seminal work of Hayami (١٩٦٩) and Hayami and Ruttan (١٩٧٠) by introducing meta-frontier function. They presented a meta-production function which encompasses all the most efficient countries in agricultural productivity in order to find the differences of productivity between developed and less-developed countries. We see that the aforementioned homogeneity constraint is no longer assumed. Latter, Battese et al (٢٠٠٤) developed meta-frontier model to estimate the production frontier function for firms operating in different regions and under different technologies. In other words this method assumes that there is a single data-generation procedure for heterogeneous firms instead of two or more data-generation process.

Even though there have been noticeable advancements in efficiency analysis theory, most of the attempts were concentrated on industrial and agricultural sectors with a few attention to technological changes in service sector. Moreover, a majority of studies in service sector only tried to explain the regional differences as a cause of heterogeneity generation between firms. In the context of current research, financial institutions have the same situation. In recent study of Bos et al. (٢٠٠٩), the Stochastic Frontier Analysis (SFA) is employed to estimate the cost frontier functions in each year and calculate the efficiency scores for banking system. Since it is not possible to assume that banks in different year are working under the same environments and regulations, the annual efficiency scores cannot be comparable. We can at most have the estimation for banks under the same frontier functions. Therefore, we cannot compare the annual cost frontier functions or simply the annual technology sets. In order to calculate technology gap, the meta-frontier analysis provides a technology set which is potentially available for whole period and for all firms.

This study utilizes the concept of meta-frontier approach for estimating the meta-frontier cost function. We consider banks in each year as a different group and estimate the annual cost frontier function using SFA. Then by estimating the most efficient cost function which is potentially available in each year (meta-frontier function), in one hand, we can calculate the distance of annual cost frontier function relative to it. This relative distance indicates the technology gap ratio for each year. In the other hand, the efficiency measurement of the meta-frontier function will be comparable for all firms and all years. Thus, the meta-frontier function enables us to estimate an efficiency measurement which is comparable for all firms working in different technologies and also the technology gap ratios which indicate the relative distance of different annual frontiers to the meta-frontier.

٣. Methodology

٣,١. Stochastic Frontier Analysis (SFA)

Stochastic Frontier Analysis (SFA) is a parametric approach in modern benchmarking models that indicates the relationship between cost and inputs prices and outputs. The prominent feature of SFA is its stochastic form that makes it different from other deterministic approaches which consider only the inefficiency error term. Aigner et al. (١٩٧٧) firstly developed SFA in production function and provided a definition of disturbance term in frontier function which is the sum of symmetric normal and half-normal random variables. Also, Meeusen and Broeck independently (١٩٧٧) proposed a composed error term (an efficiency measure and noise error term) in a Cobb-Douglas production function. According to Bogetoft and Otto (٢٠١٠), SFA method specifically supposes that the source of deviations from the cost frontier function is not only the efficiency term (such as managerial performance) but also the noise term on the value of cost such as the effects of luck, weather, measurement problems, etc. So, the cost frontier function will have an extra variable denoted by v_i . In other words, following Hasan and Marton (٢٠٠٣), in stochastic production frontier function (cost or profit function), the error term is decomposed into two elements. One component indicates the random disturbance which is assumed to have a symmetric normal distribution around the frontier and is raised from uncontrolled variables. The other component of error term which depicts the inefficiency of firms, is assumed to follow non-negative half-normal distribution above (under) the cost (profit or production) frontier and is raised from factors of management (Hasan and Marton ٢٠٠٣).
Therefore, the error term consists of two parts:v_i as a *random error term* and u_i as an *efficiency term*.Thus the cost frontier function will be expressed as:

$$\ln(C_i) = I_i\beta_i + v_i + u_i \qquad , i = ١,٢,\ldots,N.$$

Where C_i is total cost of firm ith, I_i denotes both inputs prices and outputs vectors, β_i is unknown parameter vector. The noise term (v_i) is assumed an independently and identically distributed (i.i.d) normal random variable with mean zero and constant variance $\sigma_v^٢$($v \sim N(٠,\sigma_v^٢)$). The efficiency term (u_i) is a positive independently and identically distributed (i.i.d) half-normal random variable with mean μ and variance $\sigma_u^٢$($u \sim N_+(\mu,\sigma_u^٢)$) and is independent from v_i.

Consequently, the cost efficiency will be the ratio of minimum or fully-efficient cost to the actual or observed cost of firm. This ratio is ١ for firms on the annual cost frontier function and less than one for those above the annual frontier function which we interpret them cost inefficient:

$$Cost\ Efficiency = CE = \frac{e^{I_i\beta_i + v_i}}{C_i} = \frac{e^{I_i\beta_i + v_i}}{e^{I_i\beta_i + v_i + u_i}} = e^{-u_i}$$

To estimate the unknown parameter (β_i, $\sigma_v^٢$ and $\sigma_u^٢$) in SFA models, the maximum likelihood principles will apply (Bogetoft and Otto ٢٠١٠).

٣,٢. Meta-frontier cost function

In the context of current research, for comparing firms by efficiency scores estimated by SFA, it is necessary to analyze firms operating under the same technologies or regulations. In other words, for comparing firms by these efficiency scores, they have to be homogeneous.

But for comparing firms operating under different technologies which are heterogeneous, we need a global efficiency measurement and applying SFA for this purpose has a constraint. Here, the meta-frontier cost efficiency (which released this restriction) can be helpful (Battese, Rao et al. ٢٠٠٤). The advantage of this efficiency measurement reveals when we want to have a policy implication to policy makers and authorities because it helps to have a better understanding of differences between units operating under different conditions.

The meta-frontier analysis consists of all available technologies across units over time and is defined as the minimum possible cost for available input prices and outputs. Therefore, this curve envelops each annual cost frontier functions. The functional form of meta-frontier cost function is proposed by Battese, et al. (٢٠٠٤) and expressed as:

$$\ln(C_i^*) = I_i\beta_i^* \qquad ,i = ١,٢,\ldots,N,$$

Where C_i^* is the optimal cost for bank i with a given outputs and input prices (I_i) in the considered period. Also, β_i^* indicates parameter vector in the meta-frontier cost function in which the restriction:

$$I_i\beta_i^* \leq I_i\beta_i$$

has to be satisfied. In other words, the meta-frontier cost function is a "deterministic curve" below the definite components of annual stochastic cost frontier and it must be less than or equal to the certain parts of each cost frontier in different years (Battese, Rao et al. ٢٠٠٤).

Three annual stochastic frontiers and a meta-cost frontier in case of one output are depicted in figure ١. As it is shown in the graph, the meta-frontier cost function envelops the annual stochastic frontiers and it lies below them. In other words, it is an optimal cost which is not more than the deterministic part of each stochastic frontier for different years. The frontiers A and C are relatively closer to the meta-frontier curve than the frontier B. It means that in both former cases the higher production technology is applied than in the latter one.

Insert figure ١ here

Considering the restriction that the meta-frontier cost function does not have to be more than any annual stochastic cost frontier, β^* has to be estimated in such a curve which is below all annual frontiers. Hence, meta-frontier cost function has the minimum distance to the deterministic part of the stochastic cost frontiers for different years. According to Battese, Rao et al. (٢٠٠٤) β^* derived by solving the following optimization problem:

$$\min D = \sum_{t=١}^{T}\sum_{i=١}^{N} |\ln(\hat{C}_{it}) - \ln(C_{it}^*)|$$

$$s.t. \ln(C_{it}^*) \leq \ln(\hat{C}_{it}).$$

This optimization emphasizes that the absolute distance between the meta-frontier cost function and the deterministic part of the yearly stochastic frontiers is minimized with respect to the constraint that the meta-frontier has to fall below annual cost frontiers. Substituting:

$$\ln(C_i^*) = I_i\beta_i^*$$

and

$$\ln(\hat{C}_i) = I_i\hat{\beta}_i$$

in optimization problem, produces the simpler form:

$$\min D = \sum_{t=۱}^{T} \sum_{i=۱}^{N} (I_i \hat{\beta} - \mathrm{I_i} \beta_i^*)$$

$$s.t.\ \ \mathrm{I_i}\beta_i^* \leq I_i \hat{\beta},$$

Similar to DEA approach, we can solve it by linear programming method. The beauty is that the outcome of this problem is the same as the solution of minimizing function $D^* = \bar{\mathrm{I}}\beta^*$ with respect to the restriction $\mathrm{I_i}\beta_i^* \leq I_i\hat{\beta}$. Here, $\bar{\mathrm{I}}$ is the row vector of means of elements of the $\mathrm{I_i}$-vectors for all observations in all years (Battese, Rao et al. ۲۰۰٤).

۳,۳. Meta-frontier cost efficiency and Technology Gap Ratio (TGR)

In previous subsection the meta-frontier cost function was estimated and the next step is to estimate the *meta-frontier cost efficiency ratio* and *Technology Gap Ratio (TGR).*

By meta-frontier cost function, the meta-technical efficiency can be calculated for each bank operates in different regulations and also for different years. In other words, the meta-cost frontier function helps us to calculate the technical efficiency for individual banks and consequently compare banks to each other. This efficiency measurement reflects the performance of each unit with respect to the most efficient ones (which use the minimum cost for all years).

Conventionally the cost efficiency of a firm is defined by the fraction of the *most efficient cost* relative to its *observed cost* (given the input prices and outputs). This ratio indicates the distance of the observed firm's cost to the meta-frontier cost which is adjusted by the random error term and it is expressed as:

$$\text{meta} - \text{frontier cost efficiency} = CE_i^* = \frac{C_i^*}{C_i}$$

Or in broad form:

$$CE_i^* = \frac{e^{I_i\beta_i^* + v_i}}{e^{I_i\beta_i + v_i + u_i}} = e^{-u_i} \times \frac{e^{I_i\beta_i^*}}{e^{I_i\beta_i}}$$

It is obvious from the above formulation that CE_i^* has two components:

The first term is the firm's cost efficiency derived from the annual stochastic cost frontier which is defined before:

$$CE_i = \frac{e^{I_i\beta_i + v_i}}{e^{I_i\beta_i + v_i + u_i}} = e^{-u_i}\ ,$$

Where, since u_i is a non-negative variable, it captures values between zero and one.

Figure (۲) illustrates two cases of separate *yearly cost frontier* and the *meta-cost frontier*. Each frontier indicates the minimum cost for a given output according to the available technology for that year. Point "b" shows firm i's actual cost at frontier at time $t = ۱$ where its cost efficiency is equal to ${b'I_۱}/{bI_۱}$. When it reduces its cost at time $t = ۲$ and goes to point "a", then its cost efficiency will be ${b''I_۱}/{aI_۱}$.

The second term in meta-frontier cost efficiency measurement is technology gap ratio (TGR). Battese, et al. (٢٠٠٤) introduces the following formula for calculating TGR:

$$TGR_i = \frac{e^{I_i \beta_i^*}}{e^{I_i \beta_i}}$$

Technology gap ratio is the ratio of an optimal cost (which is determined by the meta-cost frontier) with respect to the annual stochastic cost frontier. In other words, this fraction measures the relative distance between the yearly stochastic cost frontier and the meta-frontier cost function (which is optimal and most efficient cost function).Since the numerator of this fraction is less than the denominator (according to the definition of meta-cost frontier function), it has the value between zero and one; and the larger the ratio for each year is, the better the technology it uses.

According to figure ٢, since frontier at time $t =$ ١ is farther from the meta-frontier curve than at time $t =$ ٢, it burdens more cost for producing the same level of output. Thus, it uses an inferior technology than frontier at time$t =$ ٢. The TGR of firm i at point “b” under the frontier at time $t =$ ١ is equal to $b'''I_١ / b'I_١$. If it goes to point “a” at time $t =$ ٢ the TGR will be $b'''I_١ / b''I_١$ which is greater than before. So, the superior technology (frontier at time $t =$ ٢) has a greater TGR and a lower frontier cost. In fact, this ratio evaluates deviation of annual available technology from the potentially most efficient one over the whole period.

Insert figure ٢ here

As it is mentioned above, the meta-frontier cost efficiency can be written as:

$$CE_i^* = CE_i \times TGR_i \ ,$$

Where the first term is the technical cost efficiency which evaluates the distance of the firm’s observed cost relative to the yearly cost frontier. The second term implies the deviation of each specific cost frontier from the most efficient cost function for all years. Since both parts of the meta-cost efficiency have a value between zero and one, therefore it has the value in the same range.

As a result, the homogeneity assumption in measuring traditional cost efficiency (CE_i), causes some differences in the meta-frontier cost efficiency (CE_i^*). Neglect the special case of TGR=١, CE_i would be higher than CE_i^* in all situations.

٣،٤. Technology Gap Ratio as an innovation measurement

After estimating annual cost frontier function, meta-frontier cost function, efficiency ratios and technology gap ratio, the most important purpose of this study which is estimating innovation in banking system can be calculated. The method proposed by Bos, et al. (٢٠٠٩) suggests that changes in the cost frontier function during the time relative to the meta-frontier function can be considered as a proxy of innovation. Generally, firms try to minimize their cost in production process and parameters obtained under this condition indicate the status of the technology. In fact, units want to reduce their cost and thus try to improve their technology set during the time. Changing the technology set varies the technology gap and we can assume that changing in the technology gap ratio is a result of innovation.

According to figure ٢ the TGR of firm i increases by changing from the inferior cost frontier at time $\mathrm{t} =$ ١ to the superior cost frontier at time $\mathrm{t} =$ ٢. Thus, the positive changes in TGR during the time reflect innovation in firm.

٣,٥. Dynamic of technology gap ratio

To illustrate changes in TGR during the time or shortly, innovation in banking system, this thesis will apply Salter curves method. Cantner and Krüger (٢٠٠٤) developed the Salter curves to depict differential changes of economic and technological indicators by deviations of the curves during the diverse periods. More precisely, the order of units in the first period holds constant. In fact, these graph indicate the ordering of firms in the basis of a specific index (here is TGR) and draw it for several periods, allows us to compare the changes of TGR or innovation of each firm during the time.

Salter curves have two important interpretations:

- The first one is about the slope of it. Because of descending order form of firms in first period, the slope of curve would be negative and its intensity shows the heterogeneity of firms in TGR. In other words, the steeper curve represents the more heterogeneous firms in TGR criterion and vice versa.
- The second concept is about the deviation of each Salter curves from the one in previous period and shows the differential changes in TGR. As it is mentioned before, the differential changes in TGR of firm measure innovation. Thus locating the Salter curve of later period above the Salter curve in first period (holding constant the ordering form of firms in the first period) means the average TGR for firms increased and by assumption, innovation happened.

٤. Data Source and Description of variables

Before making definition about variables and the source of data, it is worth to mention that for identifying the inputs and outputs in financial institutions, there are two different approaches: ١) production approach and ٢) intermediation approach. Since banks are the mediator between depositors and borrowers, in this study the intermediation approach will be followed (Freixas and Rochet ٢٠٠٨). The stochastic cost frontier function is the one mentioned in previous chapter and it is expressed as:

$$\ln(C_i) = f(I_i, \beta_\mathrm{i})\mathrm{e}^{\mathrm{v_i}+\mathrm{u_i}} \qquad ,\mathrm{i} = ١,٢, \dots, \mathrm{N}.$$

Where I_i is the matrix of two outputs and the price of three inputs which all considered as independent variables. Two outputs of banks include total loans ($Y_١$) and total investment ($Y_٢$). Labor, fixed assets and total deposits are considered as inputs. Total cost which is shown by C_i is a dependent variable and is equal to the sum of the quantities of inputs multiplied by their prices. These aforementioned variables are the components of the balance sheet and profit & loss statements of individual banks which are gathered from US commercial banks from FDIC website (provided by Federal Deposit Insurance Corporation)[٣]. As it is mentioned above, some components of assets and liabilities of balance sheet and income & expense are selected on the intermediary approach. Because of the unavailability of inputs prices, we divide the input expenses by the quantity of inputs. In the following, there are the definitions of input prices:

٣ -https://www.fdic.gov/index.html.

Price of employees “w١” = Salaries and employee benefits expense divided by the number of full-time employees on the payroll of the bank.

Price of fixed assets “w٢” = Expenses of bank premises and fixed assets divided by Bank premises, furniture and fixtures, equipment and other assets representing bank premises owned by the institution.

Price of deposits “w٣” = Total interest expense divided by the sum of all deposits (including demand deposits, money market deposits, other savings deposits, time deposits and deposits in foreign offices).

Table ١ shows the descriptive statistics for outputs and input prices in different years for commercial banks. Data contains individual bank information and they are year-end over the period ٢٠٠٠-٢٠١٣. Number of commercial banks is declined from ١١٣٠ in year ٢٠٠٠ to ٨٥٧ in year ٢٠١٣. There are considerable differences in the mean value and standard deviations in input prices and outputs among the years.

Insert table ١ here

٥. Empirical Results

٥,١. Estimation of annual cost frontier functions

The general cost frontier function is expressed as:

$$C_i = f(I_i, \beta_i)\, e^{v_i+u_i} \qquad , i = ١,٢, \ldots, N.$$

If we assume that $f(I_i, \beta_i) = e^{I_i \beta_i}$ and I_i is a vector of functions (e.g., logarithms) of the inputs prices and outputs for the firm i according to Battese et al. (٢٠٠٤), then

$$C_i = e^{I_i \beta_i + v_i + u_i} \qquad , i = ١,٢, \ldots, N.$$

By taking the log, it will look like:

$$\ln(C_i) = I_i \beta_i + v_i + u_i \qquad , i = ١,٢, \ldots, N.$$

As noted by Bogetoft and Otto (٢٠١٠) for handling *homogeneity in input prices*, we use one of the input prices as a denominator and here the price of employees “w١” is selected. β_i is a coefficient vector of input prices and table ٢ depicts the annual estimation of unknown parameter β_i ($\beta_٠$ is intercept, $\beta_١$ and $\beta_٢$ are coefficients of price of fixed assets and price of deposits, respectively. $\beta_٣$ and $\beta_٤$ are coefficients of total loans and total investments, respectively) which are estimated by “Benchmarking” package in language programming R.

Insert table ٢ here

Appendix A consist detailed estimation results of annual cost frontier functions. For testing the null hypothesis that whether there is actually any inefficiency term in each year ($H_٠: \sigma_u^٢ = ٠$) and the alternative hypothesis which implied that the diverse costs among banks is arised from inefficiency term ($H_١: \sigma_u^٢ > ٠$), we can use the parameter $= \sqrt{\frac{\sigma_u^٢}{\sigma_v^٢}}$. Therefore, alternatively the null hypothesis would be $\lambda = ٠$. By applying t-test, we can see that in all years the null hypothesis which indicates that there is not inefficiency term would be rejected. This means that the inefficiency effects are significant for commercial banks in their annual cost frontier functions.

Results of parameters for different years show that except in few cases, most of them are statistically significant at least ١٠ percent level and coefficients have the expected signs. Thus the annual cost frontier functions which indicate the best-practice function for each year are not the same. It means that commercial banks in different years operate under various technology sets. In fact, conducting stochastic frontier analysis separately for annual levels allow us to have different empirical models for different years.

After estimating β_i and the stochastic cost frontier function, cost efficiency score for each bank is an important interest in benchmarking studies which enables us to compare banks. All the process can be done using the language programming “R” and package “Benchmarking” (Bogetoft and Otto ٢٠١٣).

Cost efficiency levels which are calculated by the cost frontier function show the deviation of each banks’ actual cost from its most efficient cost frontier function. The average cost efficiency for years under investigation show that the efficiency score in commercial banks is not very high and they are not close to the cost frontier function in different years. In other words, these numbers indicate the potential cost savings for commercial banks. For example in year ٢٠٠٨ it is only about ٥٧ percent of their actual cost which implied the ability of banks’ manager to control cost. Table ٣ shows the mean value of *technical efficiency* in different years.

Figure ٣, also illustrates the distribution of technical efficiency of commercial banks in different years from year ٢٠٠٠ till ٢٠١٣. These figures for each year depict the frequency distribution of technical efficiency in US commercial banks which are left skewed in all years. This means that a considerable number of banks have efficiency scores more than the mean value in each year. Besides, we particularly observe higher efficiency scores in yeas ٢٠٠٢ and ٢٠٠٣ which only about ١٧ percent of banks have the efficiency scores more than ٨٠ percent (and in remained years it is less than ١٧ percent).

Insert figure ٣ here

As it mentioned above, estimating cost frontier functions and technical efficiency scores is helpful if we want to compare banks in specific year under the same regulations or technologies and would not be reliable for comparison of banks working in different environments. Thus, the different conditions have to be considered in calculating efficiency scores for the purpose of evaluating the performance of banks operating under different technologies. Subsequently, it is necessary to estimate a common frontier function for all banks which takes into account this restriction. In the case of technical efficiency, it only represents the banks managers’ capability to reduce cost without confusing with other factors such as the situations that discussed above. In the following subsection, the meta-frontier cost function for banks is estimated and we can produce such efficiency scores.

٥,٢. Estimation of meta-frontier cost function

In contrast of stochastic cost frontier functions, estimating meta-frontier cost function for the whole period provide a common cost function which is potentially available for all banks in the considered period and enables us to compare firms in different years. Moreover, it takes the advantage of an analysis for technology gaps in each year relative to the accessible technology for the whole period.

The parameters of meta-frontier function which can be obtained by solving the underlying problem make the distance of the annual frontier and meta- frontier minimized. In other words, meta-frontier cost function is a deterministic parametric cost function which is not more than the deterministic part of annual stochastic cost frontier functions (Battese, Rao et al. ٢٠٠٤). Thus the *restriction* of current *problem* is that the meta-frontier function has to be below the all annual frontiers or:

$$\min D = \sum_{t=١}^{T} \sum_{i=١}^{N} (I_i \hat{\beta} - \mathrm{I_i} \beta_i^*)$$

$$s.t.\ \ \mathrm{I_i} \beta_i^* \leq I_i \hat{\beta},$$

The *solution* of this *problem* is equal to the solution of minimizing the equation $D^* = -\bar{\mathrm{I}}\beta^*$ in which $\bar{\mathrm{I}}$ is the vector of mean of input prices and outputs of all banks in all years (Battese, Rao et al. ٢٠٠٤). The *restriction* is the same as before:

$$s.t.\ \ \mathrm{I_i} \beta_i^* \leq I_i \hat{\beta},$$

This problem also can be calculated by package "lpsolve" in language programming "R" (Berkelaar ٢٠١١) which is used for linear programming. Table ٤ shows the estimation of unknown parameters of meta-frontier cost function.

Insert table ٤ here

The coefficients of meta-frontier cost function are almost different from those in the annual cost frontier function. Put differently, the meta-frontier cost function which is obtained by this procedure locates beneath all annual cost frontiers of commercial banks and is potentially available for all banks in all periods. In fact, it is the minimum cost considering the most efficient cost functions of commercial banks in the period ٢٠٠٠ to ٢٠١٣. Some stochastic frontiers are tangent to the meta-frontier function and at the same time, others have some distance to it or are above it.

٥,٣. Estimation of Technology Gap Ratio

Technology gap ratio which indicates the deviation of annual cost frontier from the meta-frontier cost function can be calculated manually. With this measurement we can compare the various technology sets applying by the commercial banks in different years. In other words, the average technology gap ratio in each year implies that how the performance of banks in one year improves comparing to banks in other years within a considered period. This measurement ranges between zero and one where one is for firms operate on the meta-frontier. Here, the average TGR for all commercial banks in the whole period is estimated ٠,٦٨. Table ٣ depicts the mean value of TGR in different years and it varies from ٠,٥٥ (in year ٢٠١٣) to ٠,٩ (in year ٢٠٠٢). These results demonstrate that in year ٢٠١٣ the commercial banks adopted inferior production technologies compare to other years. If the available technology which is associated to the meta-frontier function was applied, the commercial banks in that year could save up to ٤٥ percent of their frontier cost. In other words, even if all banks operate on the most efficient cost frontier function in year ٢٠١٣, the frontier function lags behind the meta-frontier function with gap ٥٥ percent. In contrast, in year ٢٠٠٢ the distance between the annual cost frontier and meta-frontier function is minimum and we can interpret that the superior production technologies were used in comparison to other years. Put differently, in year ٢٠٠٢ commercial banks tended to employ the most efficient production process in providing financial services. By employing the meta-frontier technology set, the potential cost saving in that year could be only ١٠ percent of their cost which reflects the highest efficiency in commercial banks for year ٢٠٠٢. In other words, it is inferred that commercial banks in this year operated nearly to the meta-frontier cost function.

Figure ٤ displays the annual frequency distribution of technology gap ratio for commercial banks over the period ٢٠٠٠ to ٢٠١٣. In fact, these figures illustrate the degree of diversities in adjusting the most efficient technology set among the years under consideration. Almost in all years the density distribution of TGR are negative skewed which means that there were a lot of banks that have TGR more than the mean value and could better adapt to the meta frontier function in each year (Wuertz ٢٠٠٩). For example in year ٢٠١١, more than ٥٤ percent of commercial banks have TGR higher than the mean value.

Insert figure ٤ here

٥,٤. Estimation of meta-frontier efficiency scores

One of the most important features of analyzing meta-frontier efficiency is that it is composed of two parts: Technical efficiency and TGR. The first component only focuses on the efficiency of each firm with respect to the relevant annual cost frontier function which is rooted from the specific performance of each firm in that year. The second part indicates the gap ratio of annual cost frontier to the meta-frontier or simply, the distance of cost frontier of each year to the most efficient frontier in the whole period.

$$CE_i^* = CE_i \times TGR_i$$

For calculating technical efficiency (CE_i) we have to consider the homogeneity of banks that operate under the same technology sets. Therefore, this measurement is higher or equal to the meta-efficiency scores (CE_i^*) which is not associated with this homogeneity restriction. Moreover, it is possible to observe different associations between technical efficiency and technology gap ratio. **I:** sometimes we may observe some banks which are technically efficient (low technically efficient) regarding to the annual cost frontier functions but their technology gap ratios (TGR) are relatively low (high). **II:** In contrast, we may find some banks with low (high) technical efficiency and at the same time have low (high) TGRs. This implies the position of banks compare to the meta-frontier cost function which depends on how efficiently they adjust to the most efficient technology set and utilize their input resources such as their human and capital resources. From this point of view, these measurements can help the authorities, policy makers and bank managers to find the causes of inefficiency for each bank in different years.

Insert table ٣ here

Table ٣ shows the average of annual cost efficiency scores, TGRs and meta-efficiency levels for the considered period. We can observe that in which direction the *technology gap ratios* and *technical efficiency* are correlated for commercial banks in different years. It discloses that in some years these two measures are negatively correlated while in other years they reveals a positively correlation. By calculating the mean value of TGRs and cost efficiency scores for the whole period, the correlation coefficient between these two average measurements estimates about ٠.٤٥. This implies that on average, in an assumed year with specific technology set (with a particular TGR) commercial banks in US can catch up ٤٥ percent of the whole change. In other words, they can capture the occasional downward movement of technology set by better adjusting their actual cost to the new cost frontier function and make their technical efficiency scores improved. Statistically, it means that on average TGR and cost efficiency of commercial banks are positively associated with each other and the strength of this linear correlation is ٤٥ percent. In other words, it might be an indicator of the ability of banks' managers in adapting to the most efficient technology set during the time by providing different financial services, more efficient money transaction mechanism and new financial instruments which reduce their costs.

This result of meta-frontier method in the yearly analysis is in contrast to the regional analysis of Battese et al. (٢٠٠٤). In their study, they attained the negative association between the mean value of cost efficiency scores and TGR for garment firms in five different regions in Indonesia. It can be inferred that in yearly analysis within a specific country, firms are more flexible to adjust their actual cost to the most efficient technology sets since they operate in the same local or regional environment. However, in regional analysis (such as done in different regions of Indonesia) firms are more consistent with their regional cost frontier function rather than adapting to the meta-frontier cost function which is the most efficient cost function for all regions. Thus, we observe regions with low (high) TGRs and high (low) technical efficiency scores.

Insert figure ٥ here

The mean value of meta-frontier efficiency scores for commercial banks over the considered period varies from ٠,٣١ in year ٢٠١٣ to ٠,٦٠ in year ٢٠٠٢. The numbers in table ٣ imply that on average, commercial banks did not operate on the meta-frontier cost function and banks' actual costs, on average, have at least ٤٠ percent distance to the most efficient cost function (meta-frontier cost function).

Insert figure ٦ here

The trend of average meta-frontier cost efficiency scores are illustrated in figure ٦. It shows that from year ٢٠٠٠ to year ٢٠٠٢, this efficiency measurement increased and is highly affected by the technology gap ratio rather than technical efficiency. This means that the technologies corresponded to these years are relatively close to the most efficient cost function for the whole period. It implies that commercial banks tried to adapt the meta-frontier function especially in year ٢٠٠٢. Put differently, in addition to their high technical efficiencies they operate under the superior technologies. In contrast, from year ٢٠٠٣ to ٢٠١٣ this score declined (except for ٢٠٠٩ and ٢٠١١ with a little increase) from ٠,٧٨٪ to ٠,٥٥٪.

Figure ٧ displays the frequency distribution of meta-efficiency scores for commercial banks in different years from year ٢٠٠٠ to ٢٠١٣.These figures illustrate that frequency distribution of meta-efficiency scores in all years are left skewed which means that a huge number of banks with meta-frontier efficiency levels more than the mean vale of the considered year. In particular, in year ٢٠٠٨ (the year corresponds to financial crisis), although this measurement is relatively low (٠,٣٧), about ٧٦ percent of commercial banks are distributed around the mean value of meta-efficiency score.

Insert figure ٧ here

٥,٥. Estimation of changes in TGR as an innovation measurement

As it is explained in section ٣.٥, I will try to visualize innovation in banking system by the changes in TGR for each firm during the time. Here, following Bos, et al. (٢٠٠٩), we assume that leaders who have the highest technology gap ratio do not innovate and the largest level of TGR will be one. In other words, the leaders are on the frontier functions and by changing the frontier functions during the time, they still on the frontier. Thus, their TGR will be one in all periods and other firms (followers) can increase their technology gap by decreasing their cost and being closer to the frontiers. In this case, the changes in technology gap ratio can be the measurement or a proxy of innovation.

Figure ٨ shows the annual average value of TGR for period ٢٠٠٠ to ٢٠١. This ratio has ٢,٨٨٪ annual growth rate and varies from ٠,٥٧ in year ٢٠٠٠ to ٠,٧٨ in year ٢٠١١. By the definition that the change in TGR is a proxy of innovation, we can say that during these years, innovation in commercial banks has happened by the increasing rate ٢,٨٨٪ per year. It is worth to mention that the average of TGR in years ٢٠١٢ and ٢٠١٣ decreased to ٠,٦٨ and ٠,٥٥ respectively which implies that the annual cost frontier function moved upward over considered years and the distance to the meta-frontier cost function is increased.

Insert figure ٨ here

In order to visualize the quantity and quality of changes of TGR in commercial banks, in continue, I applied the Salter curves method. I order banks in descending form by their total assets in year ٢٠١٣ and select the first ١٠٠ banks (large banks) as a sample. Then, for the sake of better visualizing of the changes in TGR during the time for these specific commercial banks, I divide the period under investigation to five groups in ٣-year window (except last group which is included only two years). In each group, the descending ordered TGR for these banks in year ٢٠٠٠ is considered as the basis for comparison. In other words, in subsequent periods, banks are sorted based on the ordered form in year ٢٠٠٠. In fact, the sign of slope would be negative and its quantity shows the heterogeneity of banks in TGR. Therefore, in one hand, if the Salter curve of the later period locates above (below) the Salter curve of the former period, it indicates that banks in the later period adopted better (worse) to the most efficient technology set comparing to the first period. On the other hand, if the amount of negative slope in first period is less (more) than the slope of curve in later period, it implies that heterogeneity of banks in TGR increased (decreased) in later period comparing to the former period.

Figures ٩ to ١٣ illustrate the changes of technology gap ratio for period ٢٠٠٠ to ٢٠١٣. In each figure, the blue line shows the technology gap ratio in year ٢٠٠٠ and the other ones show this ratio in following years.

The average value of TGR (for aforementioned ١٠٠ banks) in year ٢٠٠٠ is ٠.٦ which points out the average distance of its cost frontier to the meta-frontier cost function. As it is shown in figure ٩, mean value of TGR is increased to ٠.٧ and ٠,٩١ in years ٢٠٠١ and ٢٠٠٢, respectively, which implies the improvements in financial services of commercial banks and might be related to innovation in banking system, especially in year ٢٠٠٢. The lower negative slope of lines implies that in year ٢٠٠٢ technology gap ratio of commercial banks are less heterogeneous than year ٢٠٠١ and ٢٠٠٠. In fact the heterogeneity of banks decreased during this period. We can interpret this observation as the similar movements of bank's managements to hire the closer technology set to the meta-frontier cost function.

Figure ١٠ shows that the technology gap ratio in years ٢٠٠٤ and ٢٠٠٥ are almost the same in a way that both lines are located under the TGR ratio in year ٢٠٠٣. Decreasing TGR means that this period is associated with the collapse of the technology set from the superior cost frontier function in year ٢٠٠٣ to the inferior ones in years ٢٠٠٤ and ٢٠٠٥. In other words, the cost frontier function goes up and the distance between it and the most efficient cost function is increased. In addition, the Salter curve is almost horizontal which shows the homogeneity of banks in TGR.

Insert figure ٩ and ١٠ here

In the subsequent period, although TGR in ٢٠٠٧ comparing to year ٢٠٠٦ is reduced, in next year it is increased even more than the one in year ٢٠٠٦. This growth indicates some improvements in technology set. In other words, the performance of commercial banks is affected by some innovations in this period which is along with reduction or downward movement of cost frontier function in year ٢٠٠٨. Also, the same slop of Salter curves implies that the degree of heterogeneity in commercial banks did not change from ٢٠٠٦ to ٢٠٠٨.

Figure ١٢ displays changes of TGR in commercial banks in the period ٢٠٠٩ to ٢٠١١. As it is shown, this ratio in year ٢٠١٠ decreased (even less than TGR in year ٢٠٠٠ in some banks) but in the following year it is increased. It can be inferred that innovation happened where it put the annual cost frontier function somewhere close to the meta-frontier function.

The average of TGR is decreased in year ٢٠١٣, even less than year ٢٠٠٠. This means the cost frontier function in year ٢٠١٣ is close to the cost frontier function for year ٢٠٠٠. In other words, in year ٢٠١٣ commercial banks operate under an inferior technology set comparing to the meta-frontier cost function which is the most efficient cost function.

Insert figure ١١, ١٢ and ١٣ here

For comparing the trend of TGR in small banks and large banks, I sort banks by their total assets and draw the Salter curves for the last ١٠٠ banks (which are considered as small banks) in the considered period, likewise the procedure which was performed for large banks. Figure ١٤ to figure ١٨ provide a full image of the TGR for the small banks. It is obvious that there are not any considerable differences in changing the TGR between these two groups of commercial banks and we can interpret that innovation activities are almost in the same range for large and small banks. However, the heterogeneity of technology gap ratios in small commercial banks in year ٢٠٠٨ and ٢٠١٣ is more than large banks. These years are corresponded to the after great financial crisis starting in ٢٠٠٧ with significant changes in banking regulations. Therefore, it indicates that banks with lower total assets are more fragile in adjusting to the most efficient frontier function than banks with high total assets especially in corresponding financial crisis year.

Insert figure ١٤, ١٥, ١٦, ١٧ and ١٨ here

٦. Conclusion

This research tried to calculate the cost efficiency scores for banks which operate under the same technologies by SFA approach. By applying meta-frontier analysis for finding a global efficiency measurement, we compared banks which operate under different technologies and calculated Technology Gap Ratio (TGR). Finally, the trend of TGR visualized using the Salter curves which imply financial innovation in banking system.

I employed the changes of Technology Gap Ratio (TGR) as a proxy of innovation. TGRs are calculated using frontier analysis. At first step, I estimated the annual cost frontier functions and the most efficient cost frontier function (meta-frontier cost function) which is potentially available for the whole period. Then, the relative distance of annual cost frontier functions to the meta-frontier function which defined as TGR are calculated for different years.

It is discussed that the average TGR (which implies how much the technology is used in specific year lags behind the most efficient one for the whole period) has a positive correlation to the annual cost efficiency scores. It is inferred that usually, on average, the technically efficient commercial banks in one year are also technologically efficient and vice versa. This result of meta-frontier method in the yearly analysis is in contrast to the typical regional analysis. It can be inferred that in yearly analysis, firms are more flexible to adjust their actual cost to the most efficient technology set since they operate in the same local or region. However, in regional analysis firms are more consistent with their regional cost frontier function rather than adapting to the meta-frontier cost function which is the most efficient cost function for all regions.

In next step, in order to display changes of TGR for commercial banks, the Salter curves for the first ١٠٠ banks (which are selected by ordering them with respect to their total assets in year ٢٠١٣) are drawn. The considered period is divided into ٣-year time windows from ٢٠٠٠ to ٢٠١٣ and the trend of TGR investigated for each bank. The results showed that the average of TGR from ٢٠٠٠ to ٢٠١١ was associated with ٢,٨٨٪ annual growth rate which varied from ٠,٥٧ in year ٢٠٠٠ to ٠,٧٨ in year ٢٠١١. We can say that the commercial banks have experienced innovation by annual growth rate equal to ٢,٨٨٪. Even though this ratio increased in the first three years, it almost was decreasing in the following years. The meta-frontier efficiency scores have the same behavior in this period.

Comparing the Salter curves of TGR for large and small banks show that there are not any considerable differences in changing the TGR between these two groups and we can interpret that innovation activities are almost in the same range for large and small banks. However, the heterogeneity of technology gap ratios in small commercial banks in year ٢٠٠٨ and ٢٠١٣ is more than large banks. These years are corresponded to the after great financial crisis starting in ٢٠٠٧ with significant changes in banking regulations. Therefore, it indicates that banks with lower total assets are more fragile in adjusting to the most efficient frontier function than banks with high total assets especially in corresponding financial crisis year.

Comparing Salter curves for both groups of banks (large and small commercial banks) seems very useful however this interpretation is only relied on the visual comparison. Thus, for estimating the real effects of banks' size on their innovation activities, more precise empirical studies are desirable.

Finally, the empirical studies which are proposed for further investigation in this context are as follows:

i) Looking at the reasons behind the dynamics of technology gap ratios and their influences on TGRs. Changing the technological innovation in banking system (such as ATM, online-banking, etc), changing the regulations and supervisory policies (such as foreign-ownership regulations, central banking regulations, etc) and macroeconomic fluctuations can be considered as hypothetical reasons for TGR violations in banking system.

ii) Finding the real relationship between size of commercial banks and TGRs in banking system. It would be helpful to test this hypothesis by using a predefined level of significant and proper statistical methods.

iii) Investigating the effects of changes in technology gap ratios on the entry and exit rates of banks during the time. Someone may find it as an interesting topic to be discussed in the formal context of evolutionary economics.

Appendixes

Appendix ۱: Tables

Table ۱: Summary statistics for commercial banks in US for different years

Year	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
Number of banks	1,130	1,141	1,136	1,146	1,141	1,136	1,094	1,070	1,041	1,018	982	950	915	857
total cost	3.8	3.8	2.6	2.3	2.6	3.5	4.9	6.5	4.6	3.0	2.5	2.3	2.1	1.9
outputs:														
Total loans and lease (y1)	2,151	2,193	2,367	2,555	3,093	3,360	3,780	4,345	4,410	4,123	4,261	4,380	4,619	4,741
Mean	1.9	1.9	2.1	2.2	2.7	3.0	3.5	4.1	4.2	4.1	4.3	4.6	5.0	5.5
Standard deviation	15.0	14.7	16.3	17.5	22.6	26.5	32.2	37.3	38.7	37.0	40.5	43.9	46.5	49.3
Total investment securities (y2)	488	564	641	741	897	914	1,033	981	1,100	1,492	1,614	1,696	1,852	1,818
Mean	0.4	0.5	0.6	0.6	0.8	0.8	0.9	0.9	1.1	1.5	1.6	1.8	2.0	2.1
Standard deviation	2.9	3.6	4.3	5.1	7.4	8.5	9.8	9.1	11.5	16.2	17.4	18.4	20.1	19.8
Input prices (%):														
Price of employees (w1)														
Mean	45.3	47.8	53.5	51.0	54.2	55.2	62.4	62.4	61.9	63.5	65.5	66.9	76.5	77.1
Standard deviation	65.6	40.1	163.1	17.8	31.6	20.5	122.6	51.3	31.6	27.6	30.7	30.1	169.2	143.6
Price of fixed assets (w2)														
Mean	0.15	0.19	0.04	0.05	0.05	0.04	0.04	0.05	0.07	0.10	0.06	0.06	0.11	0.21
Standard deviation	2.4	3.5	0.2	0.4	0.5	0.3	0.3	0.4	0.8	1.0	0.7	0.6	1.5	3.5
Price of deposits (w3)														
Mean	0.58	0.53	0.40	0.35	0.36	0.77	1.78	3.05	2.19	0.39	0.25	0.02	1.36	0.02
Standard deviation	17.8	14.7	8.7	7.1	7.5	13.9	32.3	57.7	44.1	8.6	5.2	0.1	40.4	0.1

The refrence of data is FDIC website. All values are in millions of US dollors except input prices.

Table ۲: unknown parameters (β_i) of annual cost frontier functions

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
β_0	4.46	3.47	1.91	2.69	3.45	3.45	3.67	3.94	3.57	3.27	4.39	2.90	3.70	5.24
	(0.02)	(0.21)	(0.16)	(0.17)	(0.24)	(0.19)	(0.24)	(0.2)	(0.35)	(0.22)	(0.23)	(0.22)	(0.21)	(0.26)
β_1	0.09	0.06	0.16	-0.02	-0.17	-0.10	-0.37	-0.09	-0.30	-0.09	-0.22	-0.26	-0.20	-0.30
	(0.05)	(0.06)	(0.04)	(0.03)	(0.05)	(0.04)	(0.07)	(0.03)	(0.07)	(0.02)	(0.04)	(0.03)	(0.03)	(0.04)
β_2	-0.02	0.06	0.58	0.61	0.53	0.50	0.58	0.29	0.17	0.41	0.40	0.75	0.48	0.18
	(0.05)	(0.05)	(0.03)	(0.03)	(0.04)	(0.03)	(0.06)	(0.03)	(0.06)	(0.03)	(0.04)	(0.04)	(0.03)	(0.05)
β_3	0.57	0.65	0.62	0.64	0.64	0.66	0.63	0.66	0.60	0.60	0.64	0.64	0.66	0.62
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.02)	(0.01)	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
β_4	0.29	0.11	0.20	0.20	0.18	0.19	0.14	0.17	0.10	0.18	0.18	0.15	0.11	0.14
	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.02)

Numbers are my own calculation using package "Benchmarking" in language programming "R".

Values in parentheses are standard errors of parameters.

Table ٣: Technical efficiency, technology gap ratio and meta-frontier efficiency

year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
CE														
mean	0.65	0.60	0.66	0.67	0.64	0.63	0.59	0.62	0.57	0.61	0.62	0.61	0.59	0.58
Standard deviation	0.12	0.14	0.17	0.16	0.12	0.16	0.15	0.16	0.10	0.16	0.14	0.17	0.17	0.15
TGR														
mean	0.57	0.67	0.91	0.78	0.69	0.67	0.66	0.62	0.67	0.71	0.60	0.78	0.68	0.55
Standard deviation	0.04	0.04	0.01	0.03	0.03	0.04	0.04	0.04	0.06	0.04	0.04	0.05	0.04	0.05
CE*														
mean	0.37	0.40	0.60	0.52	0.44	0.43	0.39	0.39	0.38	0.43	0.37	0.48	0.41	0.31
Standard deviation	0.07	0.09	0.15	0.12	0.08	0.11	0.10	0.10	0.07	0.11	0.09	0.13	0.11	0.08

Numbers are my own calculation using packages "Benchmarking" and "lpsolve" in language programming "R".

CE, TGR and CE* are cost efficiency, technology gap ratio and meta-frontier cost efficiency, respectively.

Table ٤: Unknown parameters of meta-frontier cost function

β_0^*	β_1^*	β_2^*	β_3^*	β_4^*
0.86	0.00	0.50	0.58	0.20

Numbers are my own calculation using package "lpsolve" in language programming "R".

Table ٥: General statistics of meta-cost efficiency scores

year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	0.69	0.76	0.87	0.79	0.75	0.69	0.74	0.67	0.91	0.75	0.67	0.86	0.75	0.66
1. Quartile	0.36	0.37	0.54	0.47	0.42	0.38	0.35	0.35	0.37	0.38	0.34	0.41	0.35	0.28
3. Quartile	0.40	0.45	0.70	0.60	0.49	0.50	0.44	0.45	0.41	0.50	0.42	0.57	0.48	0.36
Median	0.38	0.41	0.62	0.54	0.45	0.44	0.40	0.40	0.39	0.45	0.38	0.49	0.42	0.32
Skewness	-1.63	-1.31	-1.28	-1.33	-2.02	-1.30	-1.34	-1.12	-1.26	-1.13	-1.29	-0.94	-0.74	-0.66
Kurtosis	8.52	4.38	2.35	2.77	6.69	2.66	3.08	2.27	16.57	2.33	3.53	1.47	1.31	2.64

Numbers are my own calculation using packages "fBasics" (Wuertz July 2, 2014) in language programming "R".

Table ٦: General statistics of TGR

year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Minimum	0.07	0.12	0.75	0.21	0.10	0.11	0.01	0.00	0.00	0.07	0.02	0.00	0.07	0.00
Maximum	0.92	0.91	1.00	0.84	0.78	0.76	0.79	0.83	1.00	0.85	0.76	1.00	0.83	0.73
1. Quartile	0.55	0.65	0.90	0.78	0.67	0.66	0.64	0.61	0.65	0.70	0.58	0.77	0.67	0.53
3. Quartile	0.58	0.68	0.91	0.79	0.70	0.68	0.67	0.63	0.69	0.72	0.61	0.79	0.70	0.56
Median	0.56	0.66	0.91	0.78	0.68	0.67	0.65	0.62	0.67	0.71	0.60	0.78	0.68	0.54
Skewness	-3.91	-3.73	-3.91	-15.05	-8.88	-8.30	-6.24	-6.12	-5.50	-6.61	-4.42	-17.49	-4.68	-7.42
Kurtosis	60.73	50.44	63.39	307.26	140.08	109.08	80.16	90.92	79.34	107.73	71.56	409.72	74.22	123.93

Numbers are my own calculation using packages "fBasics" (Wuertz July 2, 2014) in language programming "R".

Appendix ٢: Figures

Figure ١: Annual cost frontiers and meta-frontier cost function

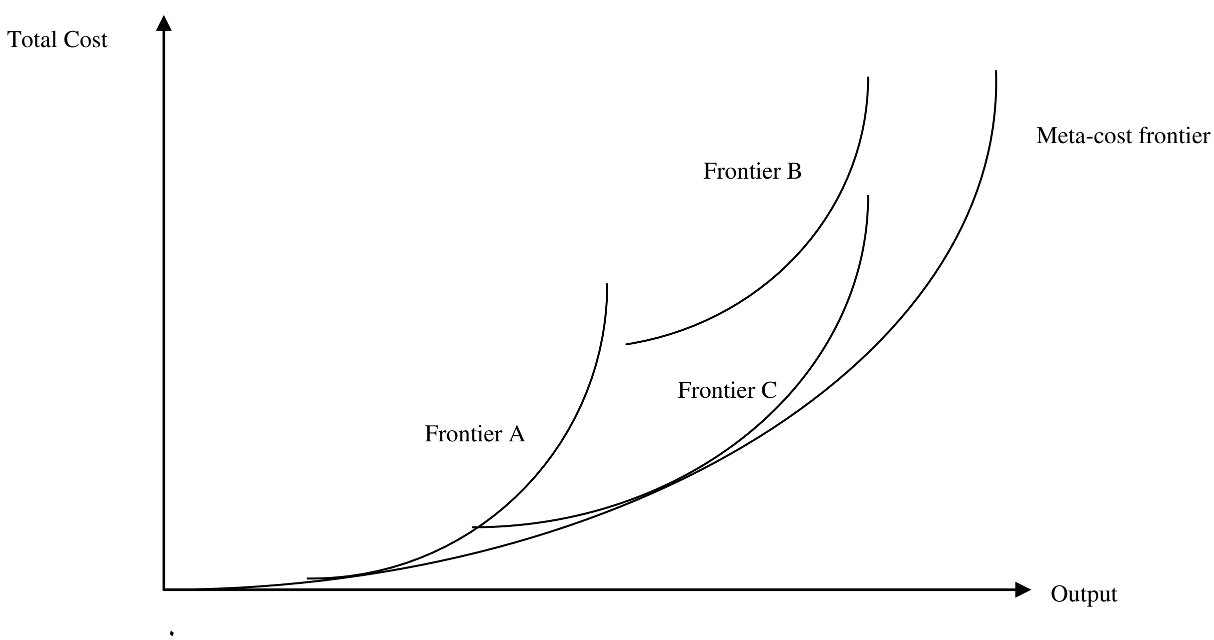


Figure ٢: Cost efficiency and TGR under different frontiers

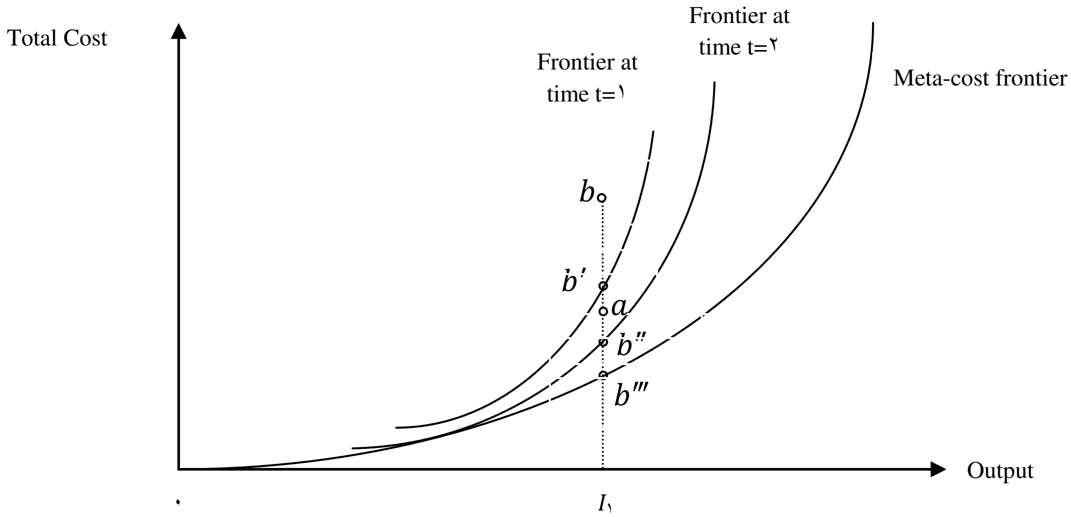
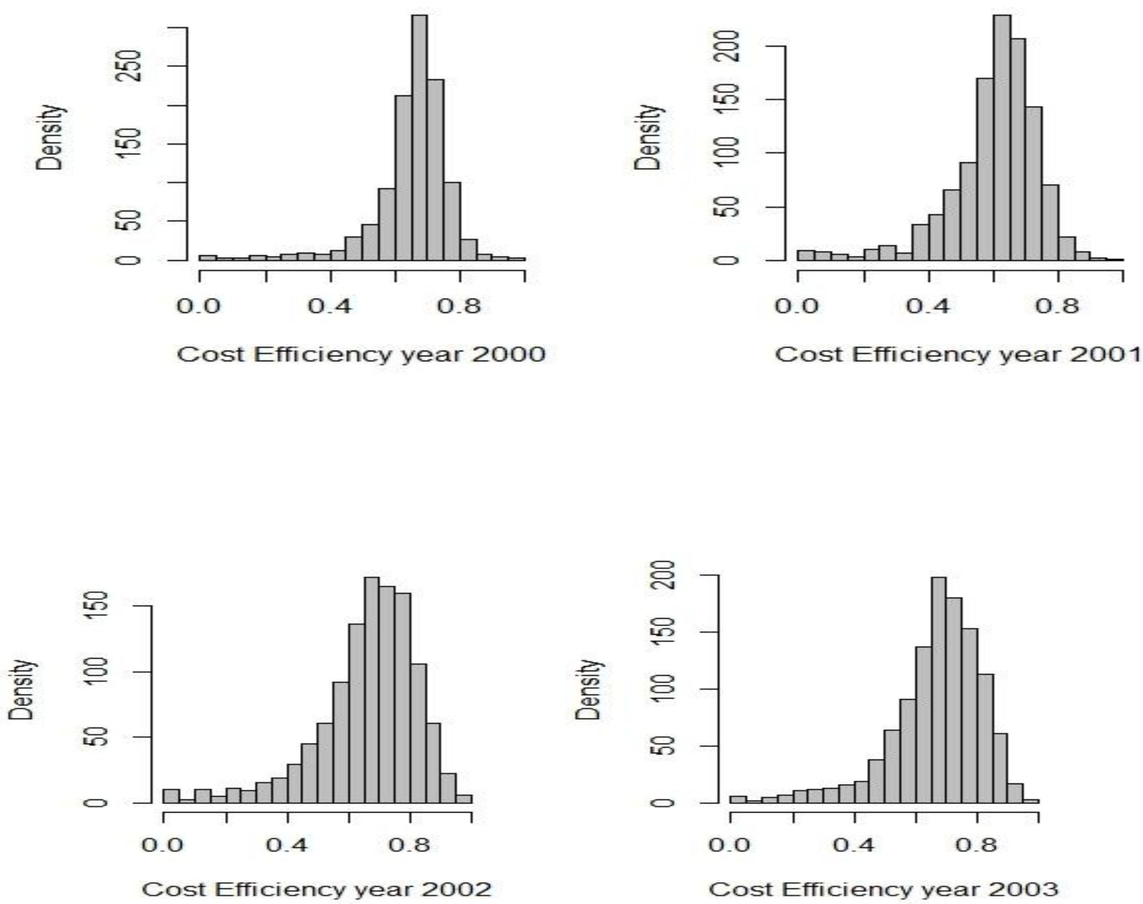
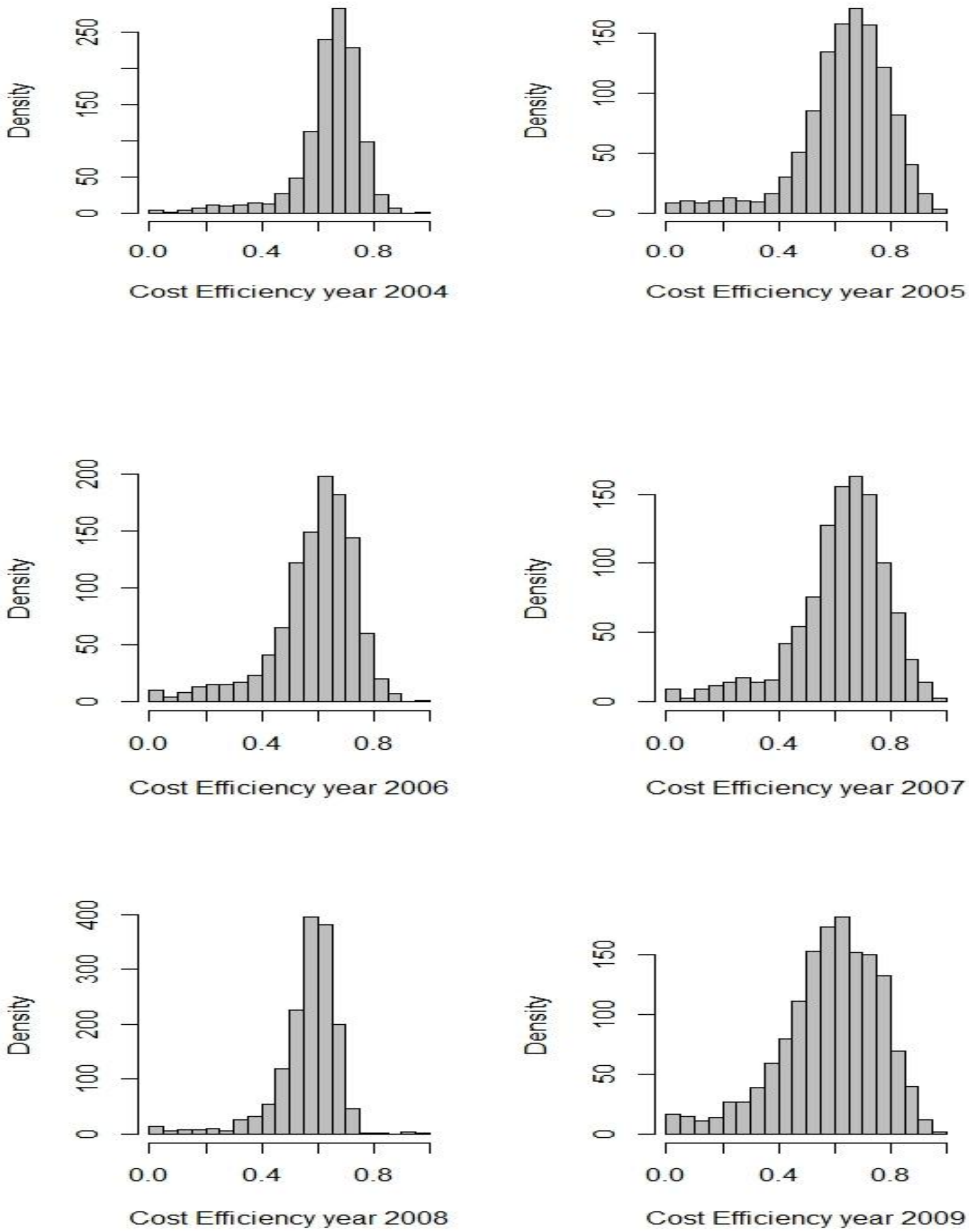


Figure ٣: Frequency Distribution of cost efficiency for years ٢٠٠٠-٢٠١٣




Density
250
150
50
0
0.0
0.4
0.8
Cost Efficiency year 2004
Density
150
100
50
0
0.0
0.4
0.8
Cost Efficiency year 2005
Density
200
150
100
50
0
0.0
0.4
0.8
Cost Efficiency year 2006
Density
150
100
50
0
0.0
0.4
0.8
Cost Efficiency year 2007
Density
400
300
200
100
0
0.0
0.4
0.8
Cost Efficiency year 2008
Density
150
100
50
0
0.0
0.4
0.8
Cost Efficiency year 2009

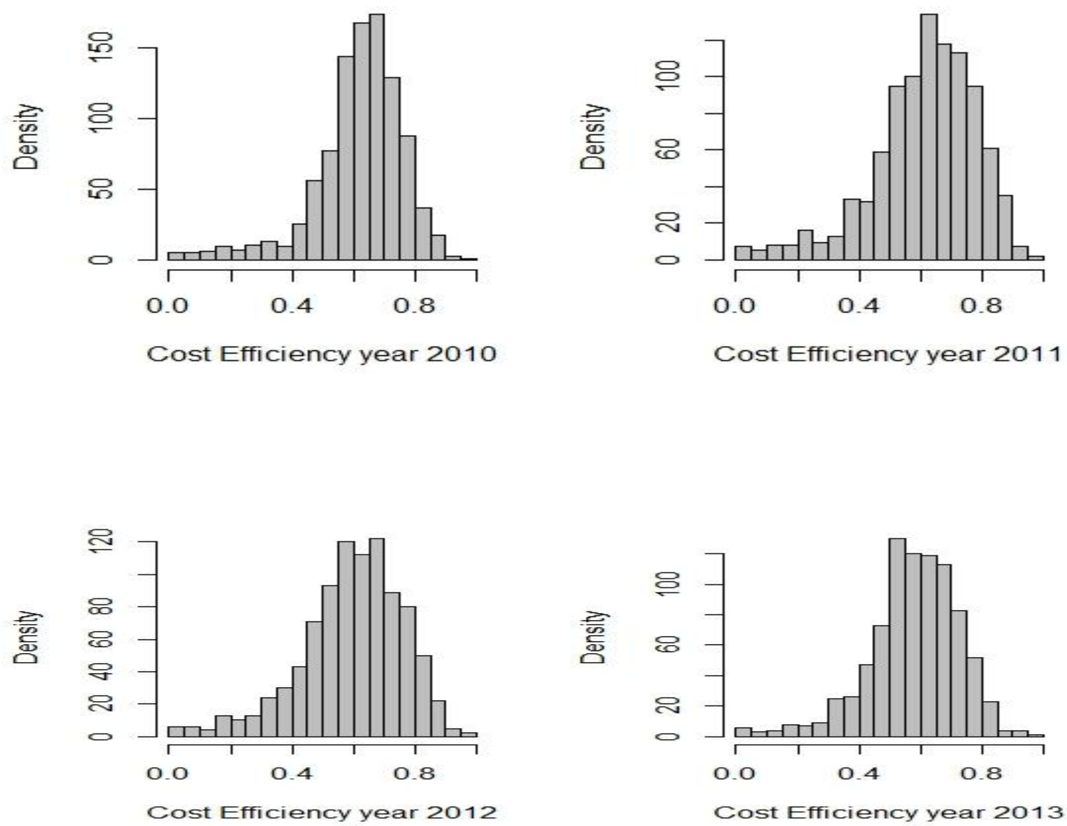
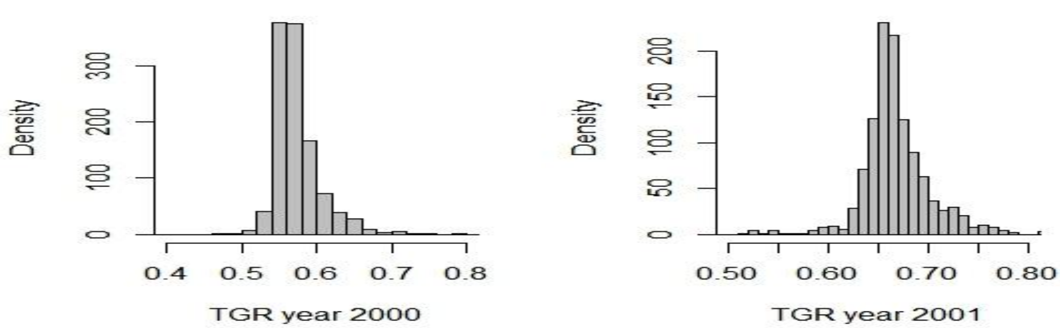
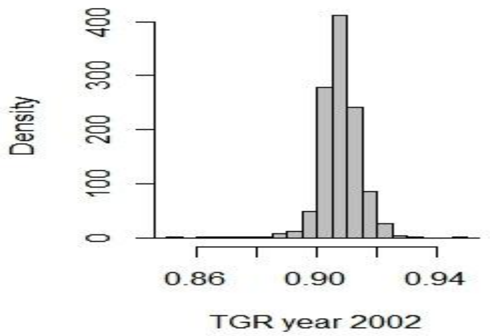
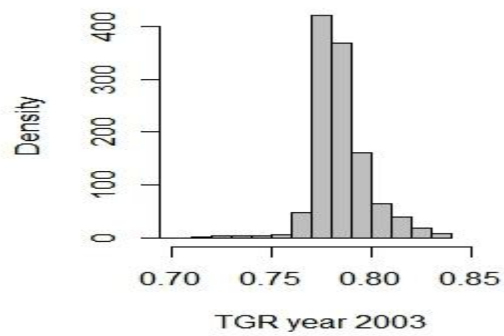
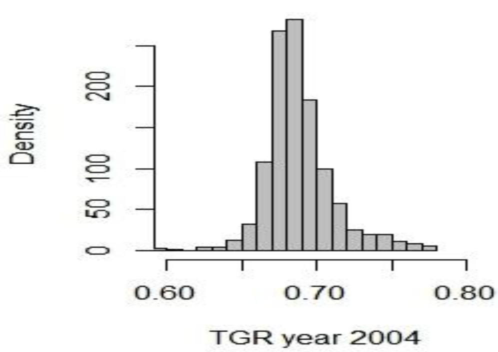


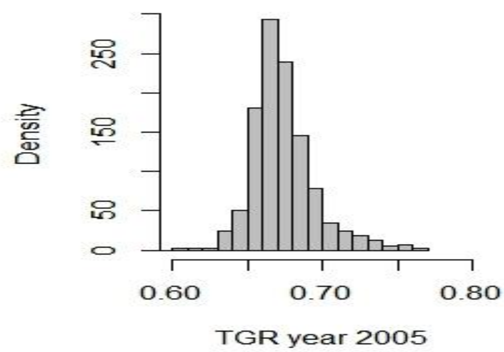
Figure ٤: Distribution of TGR for years ٢٠٠٠-٢٠١٣

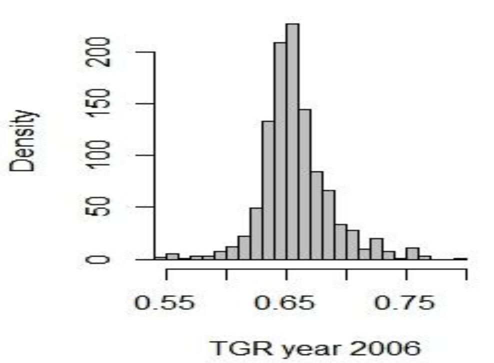


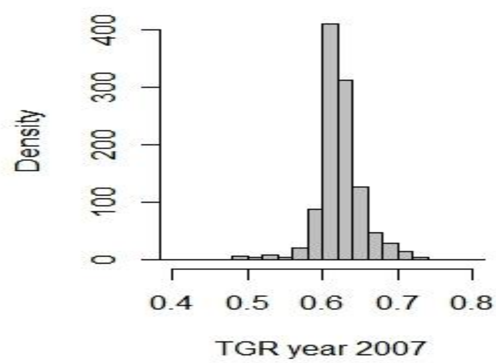

Density
0
100
200
300
400
0.86
0.90
0.94
TGR year 2002


Density
0
100
200
300
400
0.70
0.75
0.80
0.85
TGR year 2003


Density
0
50
100
200
0.60
0.70
0.80
TGR year 2004


Density
0
50
150
250
0.60
0.70
0.80
TGR year 2005


Density
0
50
100
150
200
0.55
0.65
0.75
TGR year 2006


Density
0
100
200
300
400
0.4
0.5
0.6
0.7
0.8
TGR year 2007

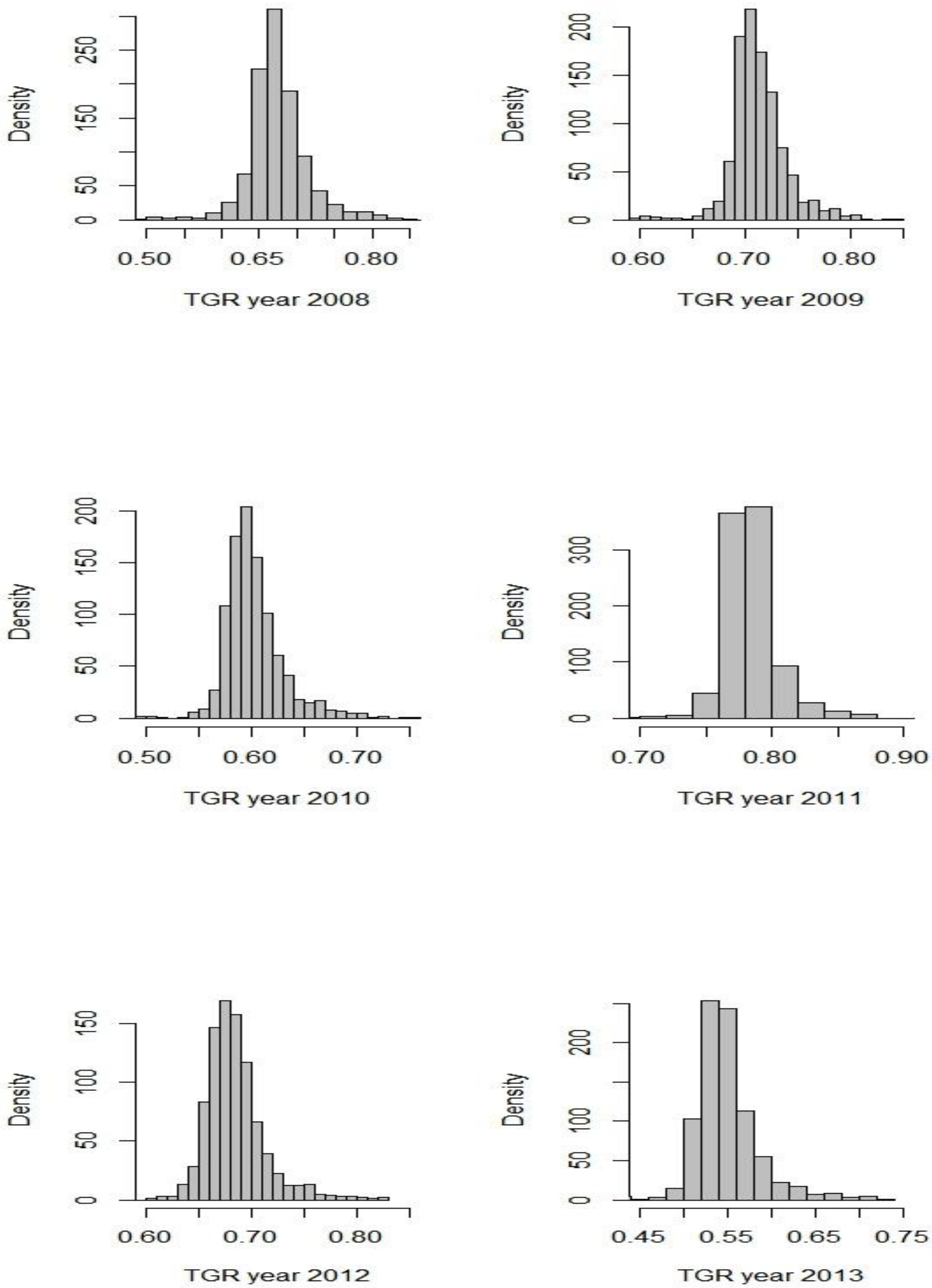


Figure ٥: Scatter plot of relating "Average of TGR" and "Average of CE"

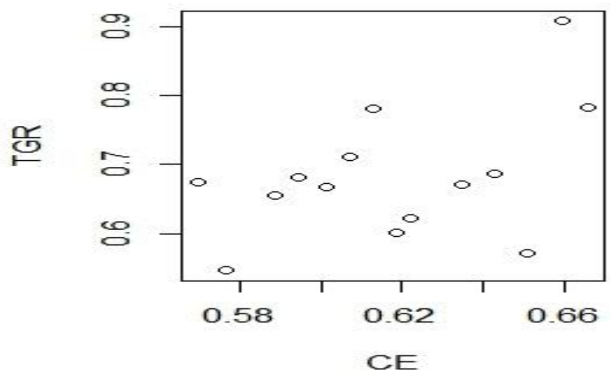


Figure ٦: Changes of average meta-frontier efficiency in years ٢٠٠٠ to ٢٠١٣

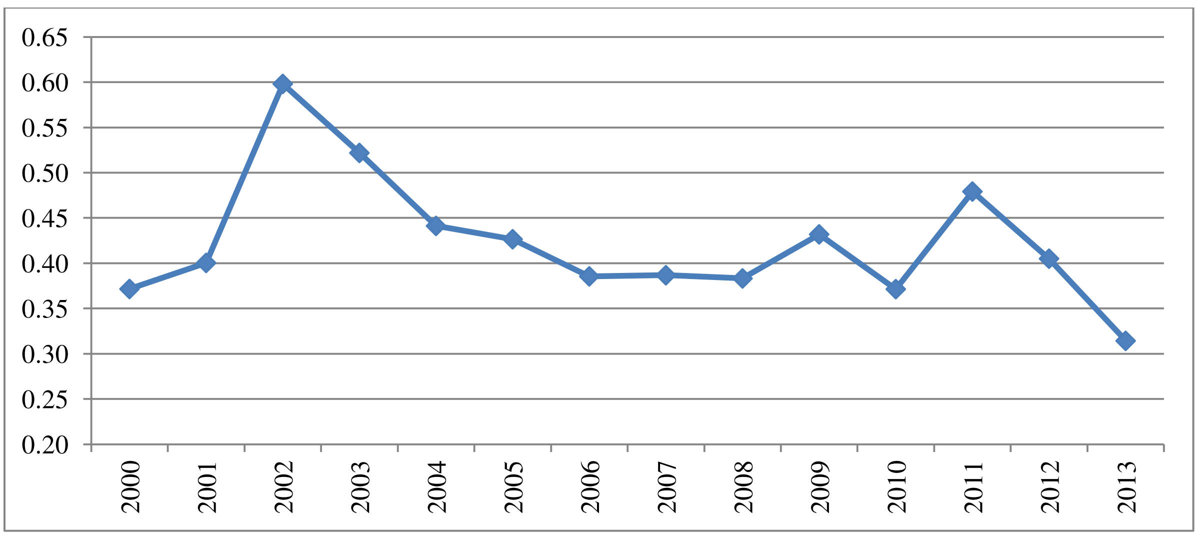
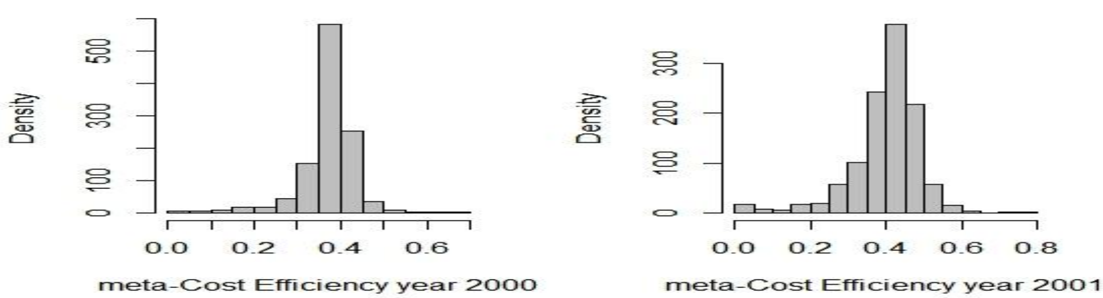
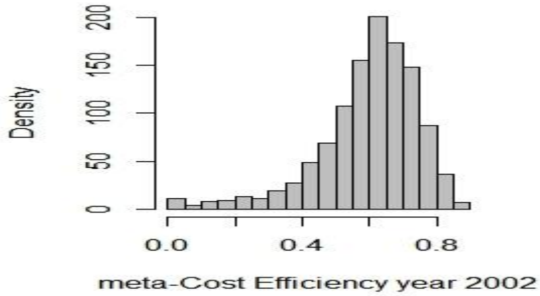
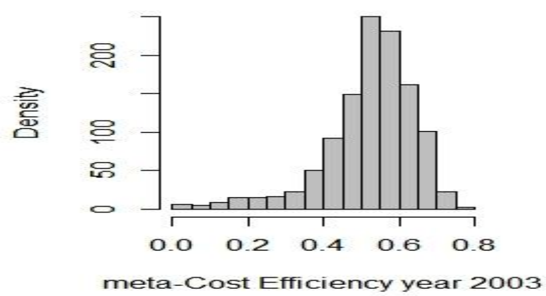
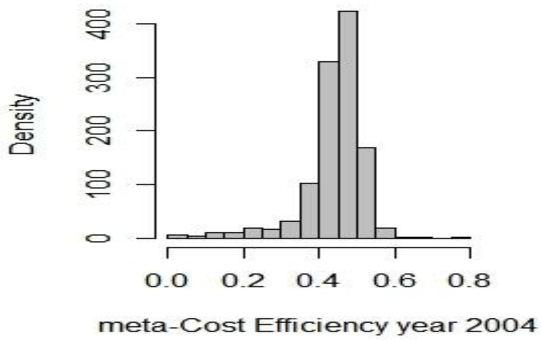


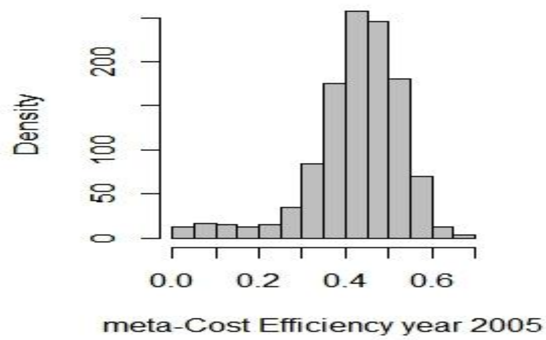
Figure ٧: Frequency Distribution of meta-cost efficiency for years ٢٠٠٠-٢٠١٣

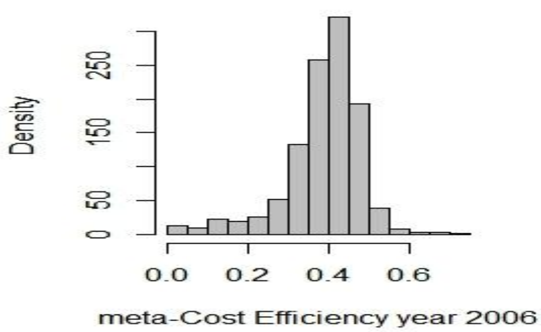


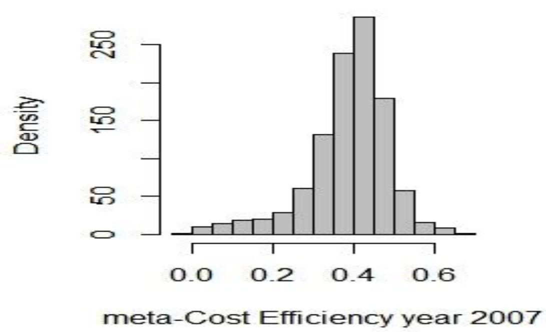

Density
0
50
100
150
200
0.0
0.4
0.8
meta-Cost Efficiency year 2002


Density
0
50
100
200
0.0
0.2
0.4
0.6
0.8
meta-Cost Efficiency year 2003


Density
0
100
200
300
400
0.0
0.2
0.4
0.6
0.8
meta-Cost Efficiency year 2004


Density
0
50
100
200
0.0
0.2
0.4
0.6
meta-Cost Efficiency year 2005


Density
0
50
150
250
0.0
0.2
0.4
0.6
meta-Cost Efficiency year 2006


Density
0
50
150
250
0.0
0.2
0.4
0.6
meta-Cost Efficiency year 2007

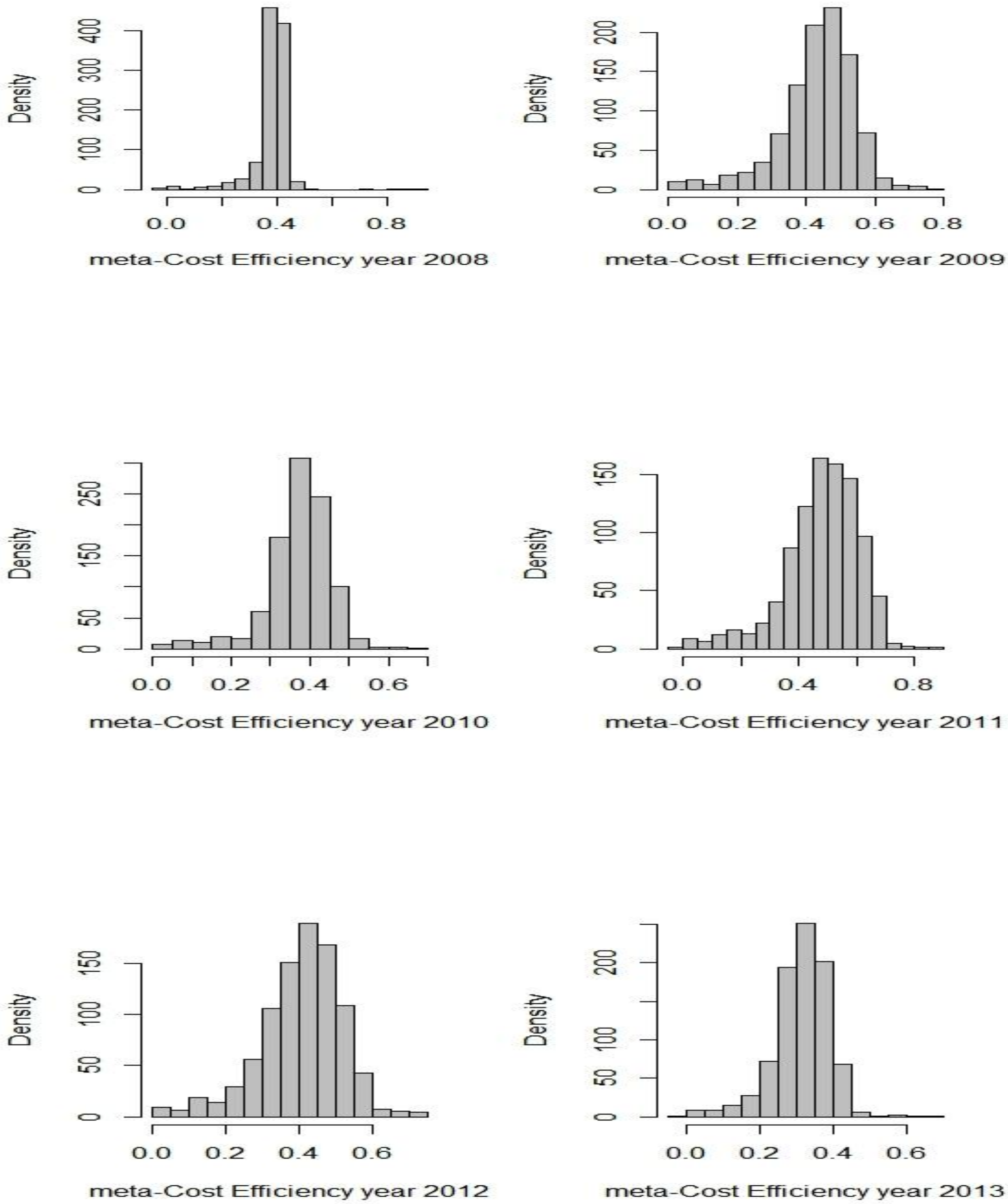


Figure ٨: Changes of average TGR in years ٢٠٠٠ to ٢٠١٣

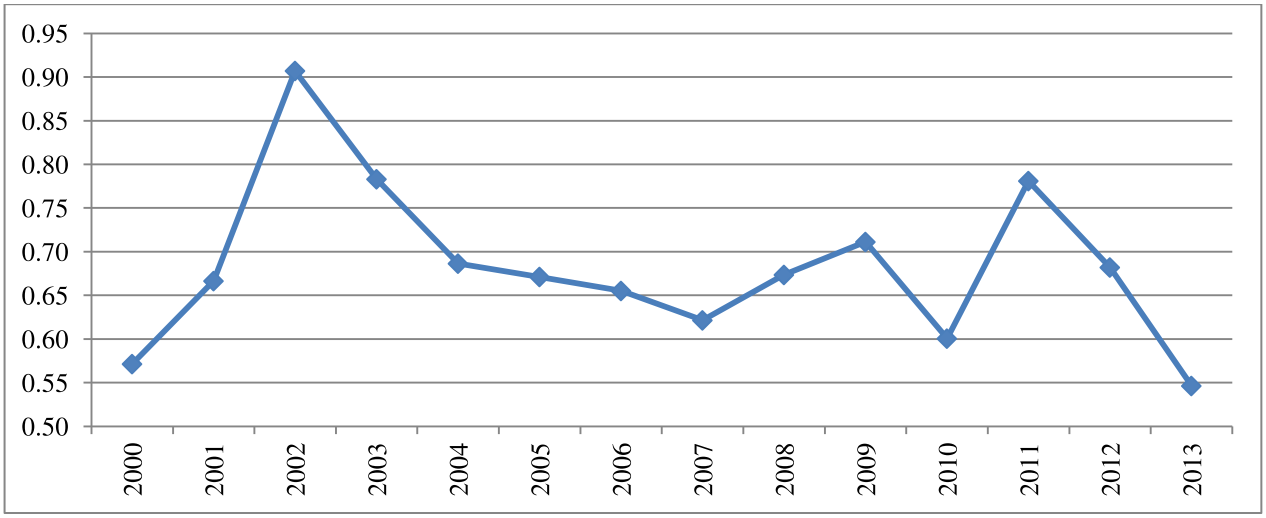
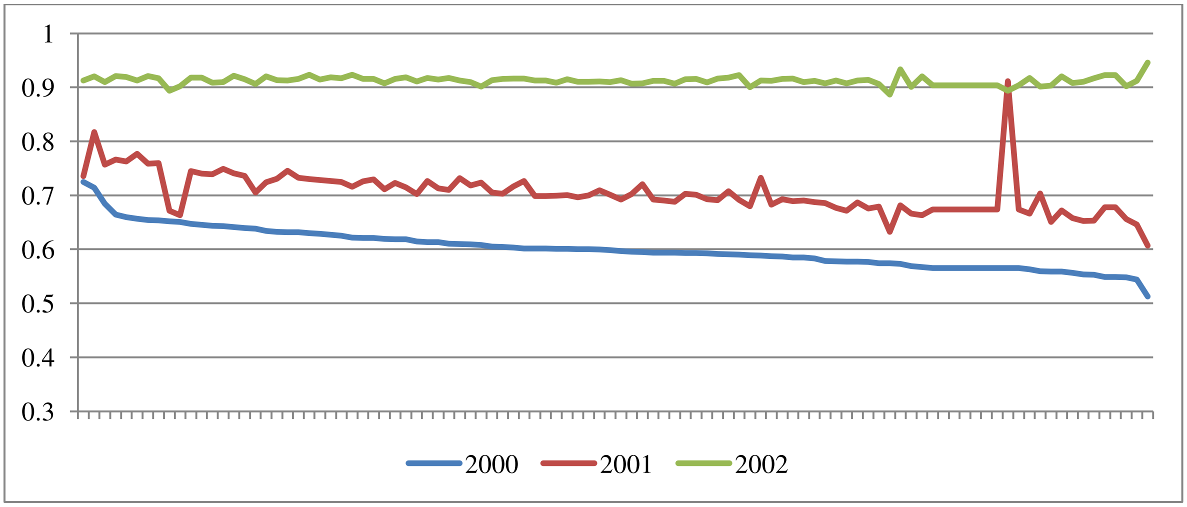
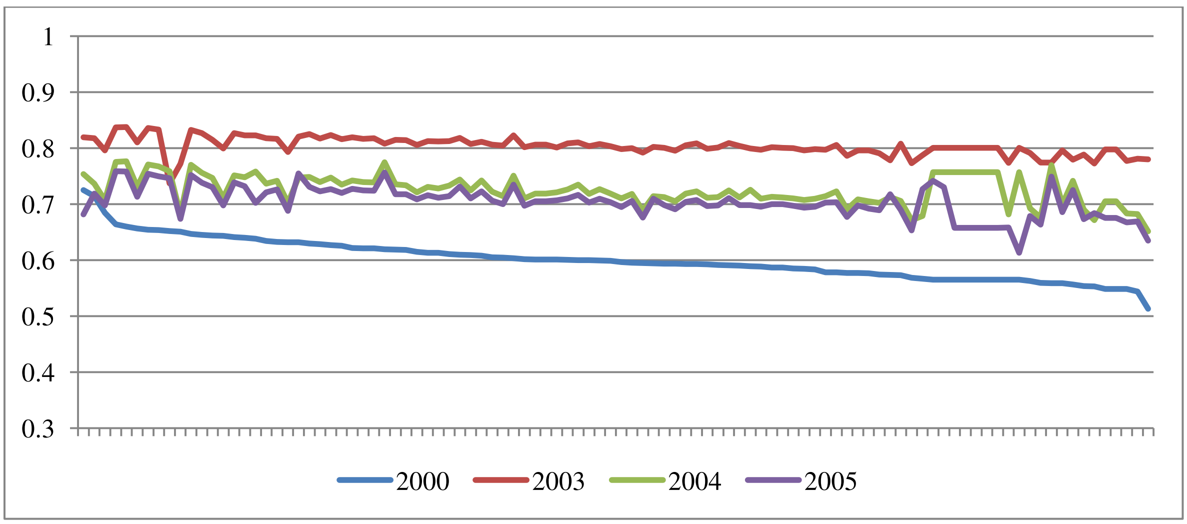


Figure ٩: Salter curves of TGR for the years ٢٠٠٠ to ٢٠٠٢



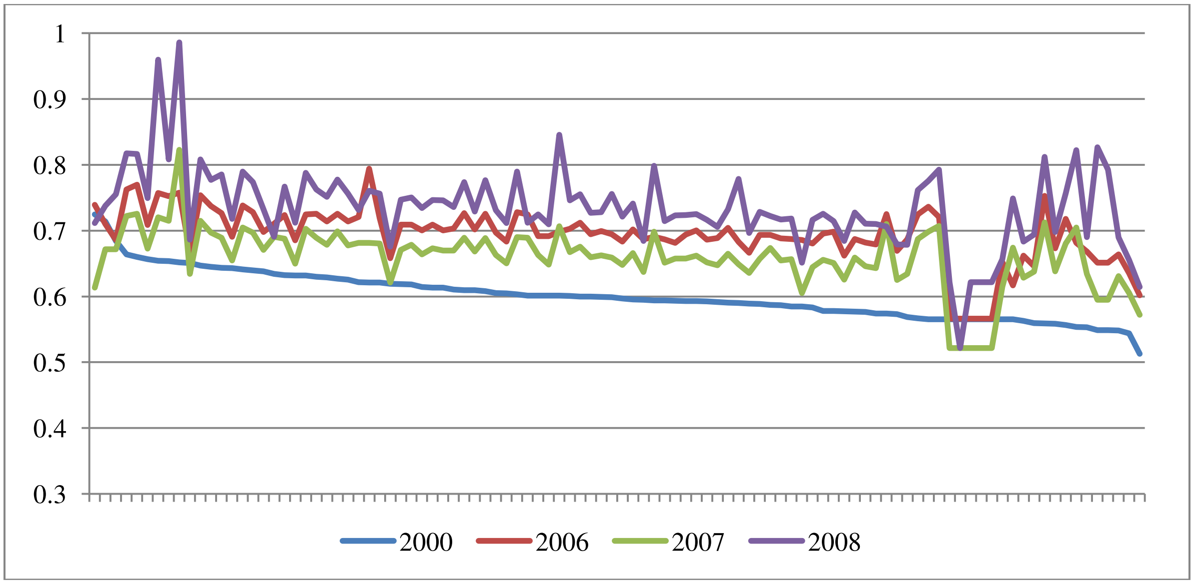
Horizontal axis denotes the first ١٠٠ banks (large banks) in a descending form based on their total assets in year ٢٠١٣ which were also active in the whole considered period. These selected banks are sorted according to the year ٢٠٠٠.

Figure ١٠: Salter curves of TGR for years ٢٠٠٣ to ٢٠٠٥



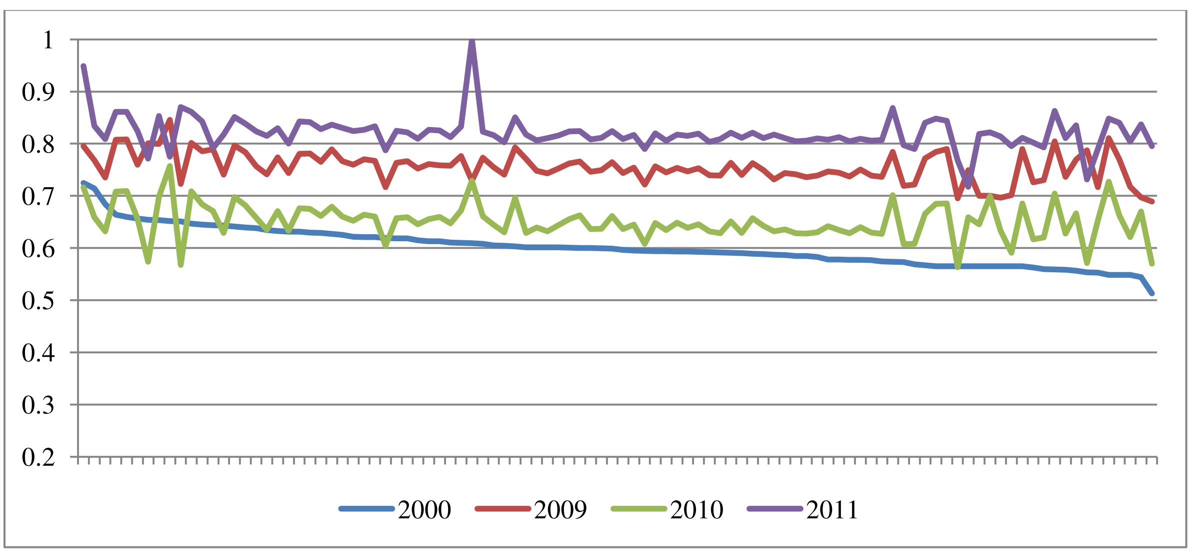
Horizontal axis denotes the first ١٠٠ banks (large banks) in a descending form based on their total assets in year ٢٠١٣ which were also active in the whole considered period. These selected banks are sorted according to the year ٢٠٠٠.

Figure ١١: Salter curves of TGR for years ٢٠٠٦ to ٢٠٠٨



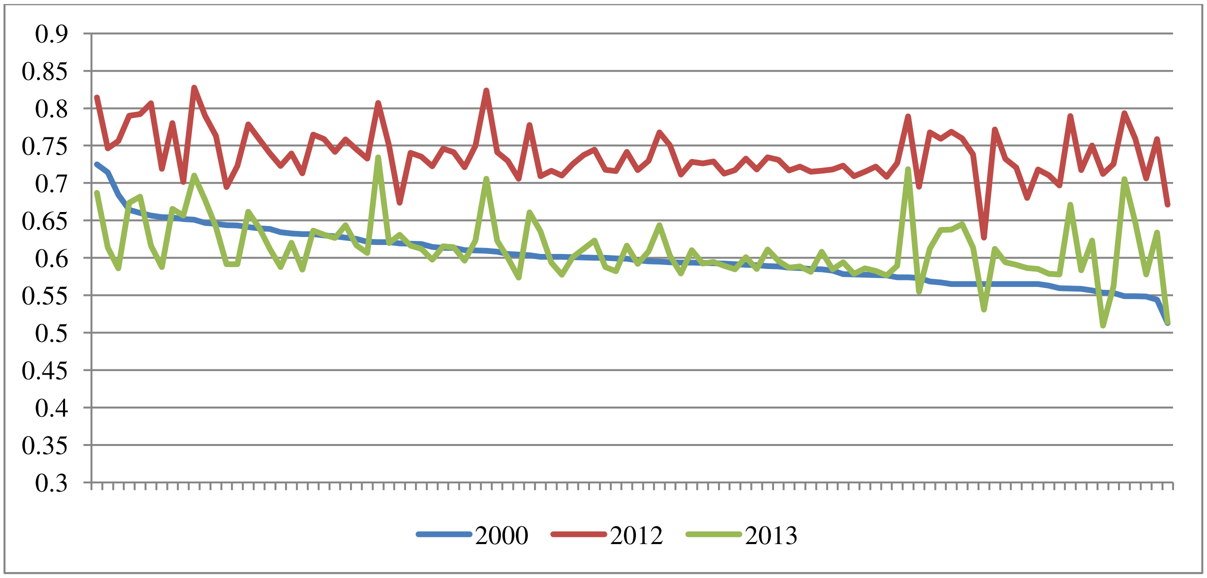
Horizontal axis denotes the first ۱۰۰ banks (large banks) in a descending form based on their total assets in year ۲۰۱۳ which were also active in the whole considered period. These selected banks are sorted according to the year ۲۰۰۰.

Figure ۱۲: Salter curves of TGR for years ۲۰۰۹ to ۲۰۱۱



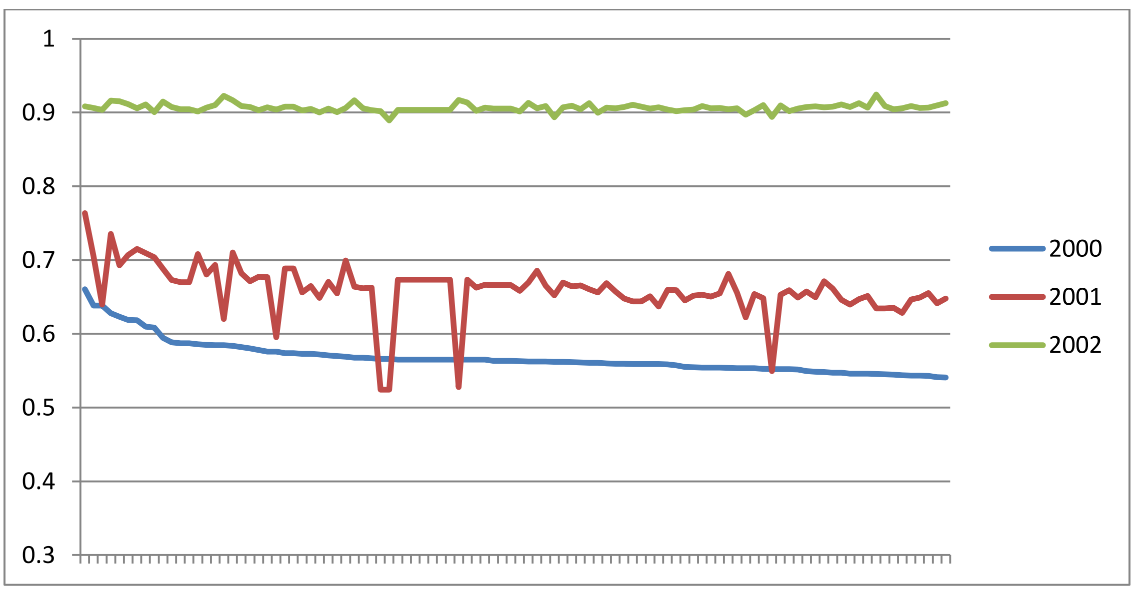
Horizontal axis denotes the first ۱۰۰ banks (large banks) in a descending form based on their total assets in year ۲۰۱۳ which were active in the whole considered period. These selected banks are sorted according to the year ۲۰۰۰.

Figure ۱۳: Salter curves of TGR for years ۲۰۱۲ to ۲۰۱۳



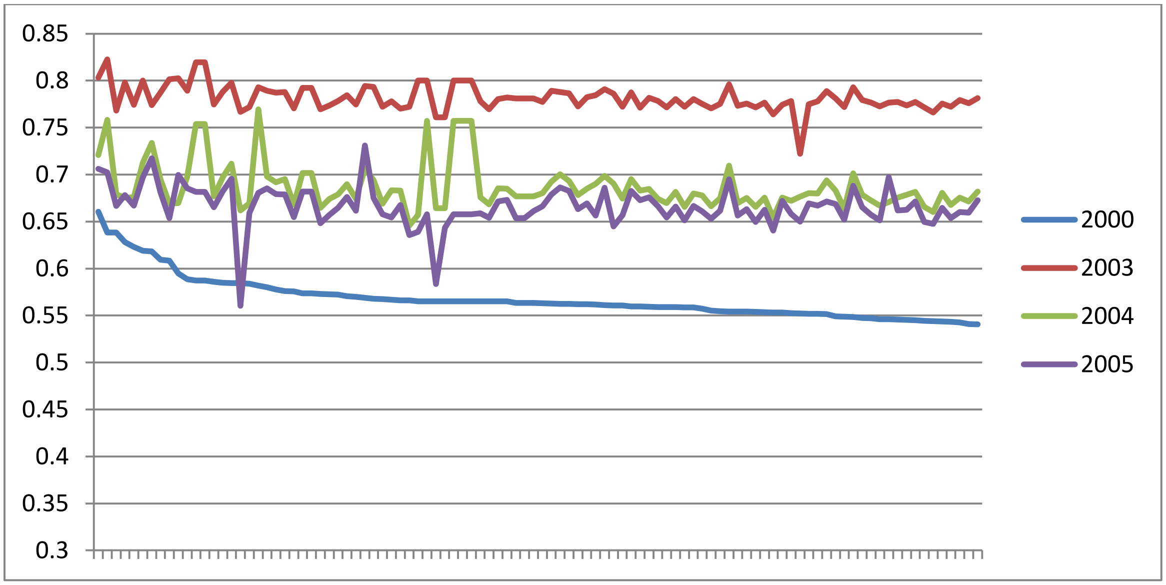
Horizontal axis denotes the first ١٠٠ banks (large banks) in a descending form based on their total assets in year ٢٠١٣ which were active in the whole considered period. These selected banks are sorted according to the year ٢٠٠٠

Figure ١٤: Salter curves of TGR for years ٢٠٠٠ to ٢٠٠٢



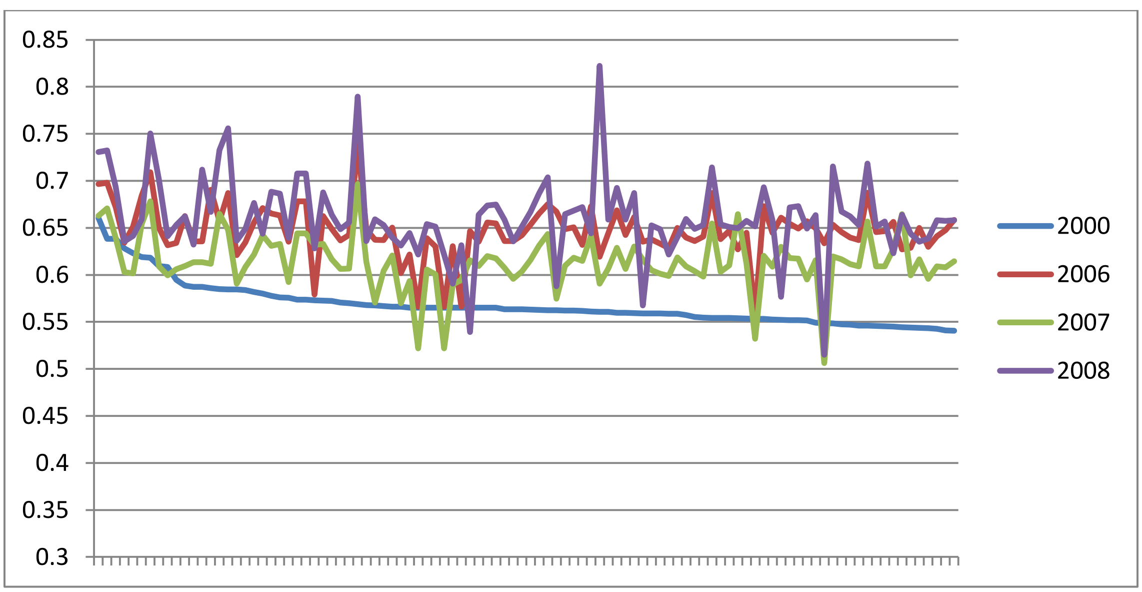
Horizontal axis denotes the last ١٠٠ banks (small banks) in a descending form based on their total assets in year ٢٠١٣ which were active in the whole considered period. These selected banks are sorted according to the year ٢٠٠٠.

Figure ١٥: Salter curves of TGR for years ٢٠٠٣ to ٢٠٠٥



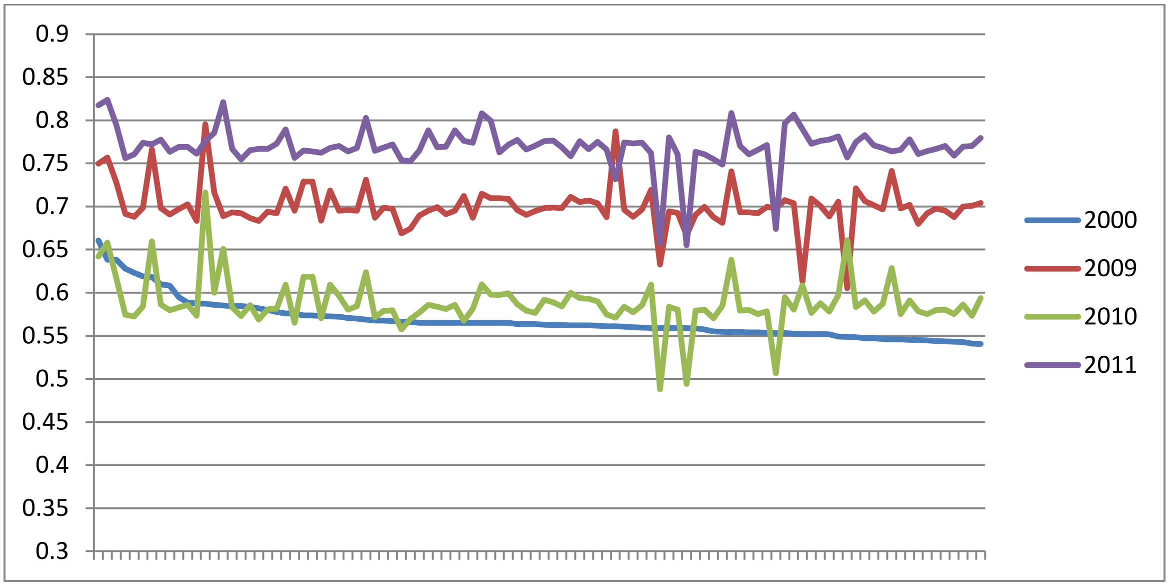
Horizontal axis denotes the last ١٠٠ banks (small banks) in a descending form based on their total assets in year ٢٠١٣ which were active in the whole considered period. These selected banks are sorted according to the year ٢٠٠٠.

Figure ١٦: Salter curves of TGR for years ٢٠٠٦ to ٢٠٠٨



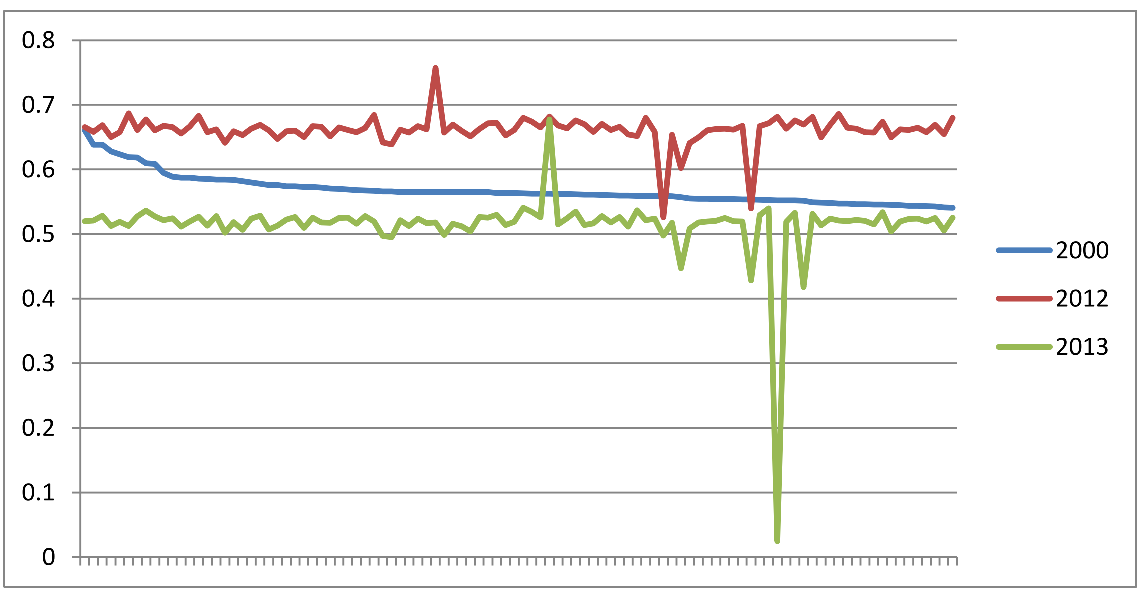
Horizontal axis denotes the last ١٠٠ banks (small banks) in a descending form based on their total assets in year ٢٠١٣ which were active in the whole considered period. These selected banks are sorted according to the year ٢٠٠٠.

Figure ١٧: Salter curves of TGR for years ٢٠٠٩ to ٢٠١١



Horizontal axis denotes the last ١٠٠ banks (small banks) in a descending form based on their total assets in year ٢٠١٣ which were active in the whole considered period. These selected banks are sorted according to the year ٢٠٠٠.

Figure ١٨: Salter curves of TGR for years ٢٠١٢ to ٢٠١٣



Horizontal axis denotes the last ١٠٠ banks (small banks) in a descending form based on their total assets in year ٢٠١٣ which were active in the whole considered period. These selected banks are sorted according to the year ٢٠٠٠.

Appendix ٣: Summary of estimation cost frontier functions in years ٢٠٠٠-٢٠١٣

Summary of cost frontier function in year ٢٠٠٠

	Parameters	Std.err	t-value	Pr(>|t|)
(Intercept)	٤,٤٦١٧٢	٠,٢٠٥٠٦	٢١,٧٥٧٧	٠,٠٠٠
xw٢	٠,٠٩٧٤٤	٠,٠٥٥٢٩	١,٧٦٢٥	٠,٠٧٨
xw٣	-٠,٠٢٤٣٢	٠,٠٥٠٥٨	-٠,٤٨٠٨	٠,٦٣٠
xy١	٠,٥٧٦١٥	٠,٠١٨٧١	٣٠,٧٩١١	٠,٠٠٠
xy٢	٠,٢٩١٨٢	٠,٠٢٠٠٧	١٤,٥٤٠٢	٠,٠٠٠
lambda	١,٧١٣٣٦	٠,١٠٦٨٤	١٦,٠٣٦٢	٠,٠٠٠
sigma٢	٠,٦١٣٠٧			

sigma٢v = ٠,١٥٥٧٧٦٣ ; sigma٢u = ٠,٤٥٧٢٩٦٦
log likelihood = -٩٤١,٩٥٦٢
Convergence = ٤

Summary of cost frontier function in year ٢٠٠١

	Parameters	Std.err	t-value	Pr(>|t|)
(Intercept)	٣,٤٧٥٩٢	٠,٢١٦١٥	١٦,٠٨١	٠,٠٠٠
xw٢	٠,٠٦٨٣٢	٠,٠٦١٥٩	١,١٠٩	٠,٢٦٧
xw٣	٠,٠٦٤٢٤	٠,٠٥٤٢٣	١,١٨٤	٠,٢٣٦
xy١	٠,٦٥٨٧٩	٠,٠١٧٥٥	٣٧,٥٤٣	٠,٠٠٠
xy٢	٠,١١٥٨٠	٠,٠١٤٤٤	٨,٠١٧	٠,٠٠٠
lambda	٢,٣٨٠٠١	٠,١٢٤٧٤	١٩,٠٨٠	٠,٠٠٠
sigma٢	٠,٨٩٢٤٤			

sigma٢v = ٠,١٣٣٩١٠٧ ; sigma٢u = ٠,٧٥٨٥٣١٥
log likelihood = -١٠٦٦,٢٢٦
Convergence = ٤

Summary of cost frontier function in year ٢٠٠٢

	Parameters	Std.err	t-value	Pr(>|t|)
(Intercept)	١,٩١١٢	٠,١٦٩٠١	١١,٣٠٨	٠
xw٢	٠,١٦٠٧	٠,٠٣٦٠٥	٤,٤٥٧	٠
xw٣	٠,٥٨١٢	٠,٠٢٧٥٣	٢١,١٠٩	٠
xy١	٠,٦٢٧٣	٠,٠١٢٤١	٥٠,٥٤٤	٠
xy٢	٠,٢٠٣١	٠,٠١٠٥٣	١٩,٢٨٢	٠
lambda	٤,٨٣٣٦	٠,٢٦٣٥٥	١٨,٣٤١	٠
sigma٢	٠,٦١٥٤٧			

sigma٢v = ٠,٠٢٥٢٦٢١٢ ; sigma٢u = ٠,٥٩٠٢١٢٥
log likelihood = -٦٩٠,٥٢٣٨
Convergence = ٤

Summary of cost frontier function in year ٢٠٠٣

	Parameters	Std.err	t-value	Pr(>|t|)
(Intercept)	٢,٦٩٠١٦	٠,١٦٦٨٢	١٦,١٢٦٥	٠,٠٠٠
xw٢	-٠,٠٢٠١٩	٠,٠٣٩٧٩	-٠,٥٠٧٤	٠,٦١١
xw٣	٠,٦٠٨٥٥	٠,٠٣٥٦٢	١٧,٠٨٥٥	٠,٠٠٠
xy١	٠,٦٤١٩١	٠,٠١٢٩٧	٤٩,٤٨٦٣	٠,٠٠٠
xy٢	٠,١٩٥٢٣	٠,٠١٠٥٢	١٨,٥٥٩٧	٠,٠٠٠
lambda	٣,٥٣٧٠١	٠,٢٠٣٨٦	١٧,٣٥٠٠	٠,٠٠٠
sigma٢	٠,٥١٤٨٦			

```
sigma٢v =  ٠,٠٣٨١٠٨٤٨ ;  sigma٢u =  ٠,٤٧٦٧٥٣٢
log likelihood =  -٦٥٤,١٧٩٦
Convergence =  ٤
```

Summary of cost frontier function in year ٢٠٠٤

```
            Parameters   Std.err   t-value  Pr(>|t|)
(Intercept)    ٣,٤٧٦٥   ٠,٢٤٠٥٠    ١٤,٤٥٥    ٠,٠٠٠
xw٢          -٠,١٧٤٠   ٠,٠٥٢٨٠   -٣,٢٩٦    ٠,٠٠١
xw٣           ٠,٥٣١٩   ٠,٠٤٢٢٨   ١٢,٥٨١    ٠,٠٠٠
xy١           ٠,٦٤٠٦   ٠,٠١٦٢٢   ٣٩,٤٨٩    ٠,٠٠٠
xy٢           ٠,١٧٩١   ٠,٠١٣٥٢   ١٣,٢٥٠    ٠,٠٠٠
lambda         ١,٨٧٦٩   ٠,١٠١١٣   ١٨,٥٦٠    ٠,٠٠٠
sigma٢         ٠,٦٥٩٤٧
sigma٢v =  ٠,١٤٥٨٠٦٣ ;  sigma٢u =  ٠,٥١٣٦٦١٣
log likelihood =  -٩٦٥,٨٧٢٢
Convergence =  ٤
```

Summary of cost frontier function in year ٢٠٠٥

```
            Parameters   Std.err   t-value  Pr(>|t|)
(Intercept)    ٣,٥٤٨٥   ٠,١٨٨٥٩    ١٨,٨١٦    ٠,٠٠٠
xw٢          -٠,١٠٤٦   ٠,٠٤٢٩٤   -٢,٤٣٥    ٠,٠١٥
xw٣           ٠,٤٩٥٥   ٠,٠٣٦١١   ١٣,٧٢٤    ٠,٠٠٠
xy١           ٠,٦٥٧٨   ٠,٠١٤٣٩   ٤٥,٦٩٩    ٠,٠٠٠
xy٢           ٠,١٨٥٦   ٠,٠١٠٩١   ١٧,٠١٨    ٠,٠٠٠
lambda         ٤,٨٢٤٥   ٠,٣١٤٤٢   ١٥,٣٤٤    ٠,٠٠٠
sigma٢         ٠,٧٨٦٢
sigma٢v =  ٠,٠٣٢٣٨٦٢٣ ;  sigma٢u =  ٠,٧٥٣٨١٣١
log likelihood =  -٨٢٥,٣٤٧٧
Convergence =  ٤
```

Summary of cost frontier function in year ٢٠٠٦

```
            Parameters   Std.err   t-value  Pr(>|t|)
(Intercept)    ٣,٦٦٥٤   ٠,٢٣٧٥٤    ١٥,٤٣١       ٠
xw٢          -٠,٣٨٦٦   ٠,٠٧٠٨٤   -٥,٤٥٧       ٠
xw٣           ٠,٥٥٧٢   ٠,٠٥٩٢٠    ٩,٤١٢       ٠
xy١           ٠,٦٣٩٠   ٠,٠١٦٩٢   ٣٧,٧٦٦       ٠
xy٢           ٠,١٤٩١   ٠,٠١٣٣٤   ١١,١٧٥       ٠
lambda         ٣,٢٥٧٦   ٠,١٧٢٩٣   ١٨,٨٣٧       ٠
sigma٢         ١,١٠٣١
sigma٢v =  ٠,٠٩٥٠٠٠٦١ ;  sigma٢u =  ١,٠٠٨١١٣
log likelihood =  -١٠٥٨,٧٢٢
Convergence =  ٤
```

Summary of cost frontier function in year ٢٠٠٧

```
            Parameters   Std.err   t-value  Pr(>|t|)
(Intercept)   ٣,٩٤٠١٧   ٠,١٩٧٥٢   ١٩,٩٤٨    ٠,٠٠٠
xw٢         -٠,٠٩٠٠٧   ٠,٠٣٣٩٢   -٢,٦٥٥    ٠,٠٠٨
xw٣          ٠,٢٨٧٢٨   ٠,٠٣١٩٧    ٨,٩٨٥    ٠,٠٠٠
```

```
xy١          ٠,٦٥٧٩٧   ٠,٠١٤٧٢   ٤٤,٧٠١    ٠,٠٠٠
xy٢          ٠,١٦٧٤٥   ٠,٠١٠٧٩   ١٥,٥١٦    ٠,٠٠٠
lambda       ٤,٥٠٥٨٣   ٠,٣٠٧١٨   ١٤,٦٦٨    ٠,٠٠٠
sigma٢       ٠,٨٥٢٨
sigma٢v = ٠,٠٤٠٠٣٢٧٥ ; sigma٢u = ٠,٨١٢٧٦٤٣
log likelihood = -٨٣٣,٠٤١١
Convergence = ٤
```

Summary of cost frontier function in year ٢٠٠٨

```
             Parameters   Std.err   t-value   Pr(>|t|)
(Intercept)  ٣,٥٦٥٧    ٠,٣٥٣١١   ١٠,٠٩٨    ٠,٠٠٠
xw٢          -٠,٢٩٩٥   ٠,٠٧٣٩٩   -٤,٠٤٧    ٠,٠٠٠
xw٣          ٠,١٧٠٨    ٠,٠٦١٩٠   ٢,٧٦٠     ٠,٠٠٥
xy١          ٠,٥٥٨٠    ٠,٠٢٠٦٨   ٢٦,٩٨١    ٠,٠٠٠
xy٢          ٠,١٠٤٥    ٠,٠١٤٧٧   ٧,٠٧٢     ٠,٠٠٠
lambda       ١,٢٩٥٦    ٠,١٢٠٤٤   ١٠,٧٥٧    ٠,٠٠٠
sigma٢       ١,٢٩٩٩
sigma٢v = ٠,٤٨٥٣١٠٧ ; sigma٢u = ٠,٨١٤٥٧٣١
log likelihood = -١٣٤٢,٢٤٦
Convergence = ٤
```

Summary of cost frontier function in year ٢٠٠٩

```
             Parameters   Std.err   t-value   Pr(>|t|)
(Intercept)  ٣,٢٧٩٨٩   ٠,٢٢٢٣٣   ١٤,٧٥٢    ٠,٠٠٠
xw٢          -٠,٠٩٤٥٣  ٠,٠٢٨٨٧   -٣,٢٧٤    ٠,٠٠١
xw٣          ٠,٤١٣٦٦   ٠,٠٣٥١٠   ١١,٧٨٦    ٠,٠٠٠
xy١          ٠,٦٠٤٩٠   ٠,٠١٤٤٨   ٤١,٧٨٦    ٠,٠٠٠
xy٢          ٠,١٧٨٦٥   ٠,٠١٠٠٨   ١٧,٧٢٥    ٠,٠٠٠
lambda       ٣,٣٣٧٦٤   ٠,٢١٢٣٤   ١٥,٧١٨    ٠,٠٠٠
sigma٢       ٠,٨٤٦٩٣
sigma٢v = ٠,٠٦٩٧٦٤٢٥ ; sigma٢u = ٠,٧٧٧١٦٣٢
log likelihood = -٨٤٤,١٣٩٣
Convergence = ٤
```

Summary of cost frontier function in year ٢٠١٠

```
             Parameters   Std.err   t-value   Pr(>|t|)
(Intercept)  ٤,٣٨٩٧    ٠,٢٣١٤٨   ١٨,٩٦٤    ٠
xw٢          -٠,٢١٨٥   ٠,٠٣٥٣٤   -٦,١٨١    ٠
xw٣          ٠,٤٠٠٥    ٠,٠٣٨٨٠   ١٠,٣٢٢    ٠
xy١          ٠,٦٤٣٠    ٠,٠١٤٥١   ٤٤,٣٢٠    ٠
xy٢          ٠,١٧٧٨    ٠,٠١١١٧   ١٥,٩١٨    ٠
lambda       ٢,٧٣٤١    ٠,١٤٧٠٥   ١٨,٥٩٢    ٠
sigma٢       ٠,٧٨١٢٧
sigma٢v = ٠,٠٩٢١٨٥١٨ ; sigma٢u = ٠,٦٨٩٠٨٨٦
log likelihood = -٨١٦,٦٩٣١
Convergence = ٤
```

Summary of cost frontier function in year ٢٠١١

```
             Parameters   Std.err   t-value   Pr(>|t|)
```

(Intercept)	٢,٨٨٢٣	٠,٢٢٩٤٣	١٢,٥٦٣	٠
xw٢	-٠,٢٦٣٧	٠,٠٣٠٩٣	-٨,٥٢٣	٠
xw٣	٠,٧٤٥٤	٠,٠٤٥٣٦	١٦,٤٣٤	٠
xy١	٠,٦٣٩٥	٠,٠١٣٧٥	٤٦,٥٢٢	٠
xy٢	٠,١٤٧٨	٠,٠١٠١١	١٤,٦٢٣	٠
lambda	٤,٠٦٦٦	٠,٢٨٣٣٤	١٤,٣٥٢	٠
sigma٢	٠,٨١٥٨٤			

sigma٢v = ٠,٠٤٦٥١٩٦٩ ; sigma٢u = ٠,٧٦٩٣٢٢٤
log likelihood = -٧٣٦,٨٦٣٧
Convergence = ٤

Summary of cost frontier function in year ٢٠١٢

	Parameters	Std.err	t-value	Pr(>|t|)
(Intercept)	٣,٧٠٠٥	٠,٢١٤٦١	١٧,٢٤٣	٠
xw٢	-٠,١٩٨٤	٠,٠٣١٢٥	-٦,٣٤٧	٠
xw٣	٠,٤٧٩٠	٠,٠٣٦٢٦	١٣,٢١١	٠
xy١	٠,٦٦٠٧	٠,٠١٦٨٤	٣٩,٢٤١	٠
xy٢	٠,١١٠٩	٠,٠١٣٨٣	٨,٠١٩	٠
lambda	٣,٣٧٥٠	٠,٢٢١٩٣	١٥,٢٠٧	٠
sigma٢	٠,٨٧٩١٥			

sigma٢v = ٠,٠٧٠٩٥٣٥٢ ; sigma٢u = ٠,٨٠٨١٩٥
log likelihood = -٧٧٤,٨١٤٤
Convergence = ٤

Summary of cost frontier function in year ٢٠١٣

	Parameters	Std.err	t-value	Pr(>|t|)
(Intercept)	٥,٢٤٢٦	٠,٢٦٠٣٣	٢٠,١٣٨	٠
xw٢	-٠,٢٨٨٥	٠,٠٣٩٣٩	-٧,٣٢٣	٠
xw٣	٠,١٧٨٥	٠,٠٥٠٢٧	٣,٥٥١	٠
xy١	٠,٦١٦٩	٠,٠١٨٤٣	٣٣,٤٧٢	٠
xy٢	٠,١٤١٧	٠,٠١٥٤٦	٩,١٦٦	٠
lambda	٢,٦٥٢٥	٠,١٧٢١٦	١٥,٤٠٨	٠
sigma٢	١,٠٢٨٨			

sigma٢v = ٠,١٢٨٠٢٤٢ ; sigma٢u = ٠,٩٠٠٧٧٩٧
log likelihood = -٨٣٤,٨٧٦
Convergence = ٤

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