國立交通大學

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碩士論文

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Estimation of Technical Efficiency and Technology Gaps for Banks in 16 European Countries Using a Meta-frontier Cost Function

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摘要

本篇論文主要欲探討歐洲 16 個國家商業銀行的成本效率，但是，在過去的研究中並無法針對不同生產技術下的銀行直接做效率的比較，所以我們便利用了 Battese、Rao 和 O’donnell (2004)所提出的共同函數模型來當我們研究的基礎，其模型主要建立在不同技術下的效率研究。而在實證的資料中，我們發現了歐洲 16 國中彼此的生產技術的確存在顯著的差異，並且各銀行的技術亦也有大幅的波動。

關鍵字：技術效率；技術缺口；隨機邊界成本函數；共同邊界成本函數；線性規劃；二次規劃

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ABSTRACT

In this thesis, we will investigate the cost efficiency of commercial banks across 16 European countries. It is important to note that the technical efficiency of a bank operating under a type of technology is not directly comparable with that of other bank operating under a different type of technology. Therefire, we adopt a meta-frontier production function, proposed by Battese, Rao, and O'donnell (2004), which allows for the calculation of technical efficiencies for banks operating under different technologies.

Keywords: Technical Efficiency; Technology Gaps; Stochastic frontier cost function; Meta-frontier Cost Function; Linear programming; Quadratic programming

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一眨眼，兩年的時光便以消逝，而待在交大財金所的日子也到了尾聲，在此求學的過程讓我對生命有了新的體悟，甚至這裡的環境、教學、師長、同學和學弟妹都在我生命中亦佔有了不可抹滅的影響，我亦很高興能走此一遭。這次論文的完成，首先我要感謝黃台心老師，在這段時間，每當我在理論、資料或是程式遇到障礙時，我總是不斷的麻煩老師，但老師總是不厭其煩的為我解惑，對此我深深感激，再來，我要謝謝鍾惠民老師，總是不斷關心我論文的進度，亦給了我不少在研究上的值得索思想法，還有我要謝謝此次論文的口試委員：傅祖壇老師和陳忠榮老師，給了我不少值得研究的方向，讓我的論文更趨完善。

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邱柏豪　謹誌於
交通大學財務金融所
民國九十五年六月

Content

1. Introduction

Following the disasters of the First World War and the Second World War, the incentive for peaceful unification through collaboration and equality of member states greatly increased. These increasing impulses of achieving the formation of the EU were come from the thirst for rebuilding Europe and expectation to get rid of the possibility of another such terrible war arising again. As a result, this momentum led to the establishment of the European Coal and Steel Community by West Germany, France, Italy and Benelux countries. Then, the European Union or EU was founded in 1992 by Treaty of European Union (the Maastricht Treaty).[1]

The Treaty of Maastricht in 1992 also sets up the European Economic and Monetary Union (EMU).[2] In economics, a monetary union is an agreement that member countries utilize a common currency among them. The EMU not only creates a single currency, the Euro, but also sets a lot of economic convergence principles, including exchange rate, inflation rate, public finance and interest rates stability. All member states of the European Union have a hand in the EMU. In the recent years, through the endeavor of the EMU, many member states have adopted the new criteria to regulate their financial markets in order to lower barriers to competition among financial institutions. For example, a bank will only be regulated by its home country even though it plans to open a new branch in any other country. All these changes help intensify the degree of competition in European financial markets. Lower production cost and higher economic efficiency may result.

As the financial markets become more and more competitive and integrated, each country's banking structure and oncoming competitive viability are greatly

[1] The Maastricht Treaty (formally, the Treaty on European Union) was signed on 7 February 1992 in Maastricht between the members of the European Community and entered into force on 1 November 1993, under the Delors Commission.

[2] EMU is sometimes misinterpreted to mean the European Monetary Unions.

determined by the current differences in managerial performance. Therefore, it is important to understand what are the differences or similarities in the production efficiency of banks among countries. In this thesis, we will investigate the cost efficiency of commercial banks across 16 European countries. It is important to note that the technical efficiency of a bank operating under a type of technology is not directly comparable with that of other bank operating under a different type of technology. However, the conventional studies on the comparisons of production efficiency are unable to distinguish the possibilities of various technologies employed by sample firms. Therefore, we adopt a meta-frontier production function, proposed by Battese, Rao, and O'donnell (2004), which allows for the calculation of technical efficiencies for banks operating under different technologies.

The thesis is organized as follows. Chapter 2 is the literature review. Chapter 3 develops a meta-frontier cost function under a one-stage process. In chapter 4, the data and the definitions of input and output variables are described, while in chapter 5 technical efficiencies for banks and technology gaps for countries are empirically evaluated in a context of meta-frontier cost methodology. The last chapter concludes the thesis.

2. Literature Review

2.1 Efficiency studies on European Banking

In the recent years the structure of European banking has been changing rapidly. The implementation of the Single Banking Market during the nineties lowered barriers to competition among European banks and helped them to expand branches abroad within the members of European Union more easily. The financial markets have become more and more competitive and integrated. Therefore, it is important to understand the sources of the banks' efficiency differences among countries.

There are three main approaches to measure technical efficiency of individual banks, the stochastic frontier approach (SFA), the distribution-free approach (DFA) and the data envelopment analysis (DEA). The SFA, developed by Aigner et al. (1977) and applied to the bank industry by Ferrier and Lovell (1990), needs to specify a particular function form, and its error term is composed of two elements. One of them represents the production inefficiency, which is usually assumed to be disturbed as a truncated or half-normal distribution, and the other follows a symmetric normal distribution. The former error term is nonnegative by construction and is used to reflect production inefficiency. Altunbas et al. (2001) applied the flexible Fourier functional form to the stochastic cost frontier function and found that banks of all sizes could save their cost by reducing managerial and other inefficiencies. Vennet (2002) analyzed the cost and profit efficiency of European financial conglomerates and universal banks and found that the trend toward de-specialization may lead to a more efficient banking system. Bonin et al. (2005) and Fries et al. (2005) applied the SFA model to investigate the bank efficiency in transition countries. They found that private banks are more efficient than government-owned banks and, foreign-owned banks are more efficient than other types of banks.

The DFA, proposed Berger (1993), assumes that the inefficiency of each bank is firm specific and constant over time in the context of panel data. Then, each firm's production inefficiency is measured as the difference between its fixed effect estimate and that of the best practice bank. The distribution of inefficiencies in the DFA model can follow almost any form, as long as they are non-negative. Maudos et al. (2002) employed the DFA approach to make cross-country comparison and uncovered that there is a wide range of variation in efficiency levels in the banking system of the European Union, especially the variation in profit efficiency being greater than in cost efficiency.

Finally, DEA imposes less structure on the efficiency frontier than does the parametric approach, because it does not need to specify any functional form for the frontier. However, it is frequently criticized as ignoring the error term. Consequently, the estimates of inefficiency using DEA are unable to distinguish the stochastic component from the efficiency measure. Berg et al. (1993, 1995) used DEA to capture the differences or similarities in the efficiency of banks among the Nordic countries. Lozano-Vivas et al. (2001, 2002) and Ana et al. (2002) improved the conventional DEA model by incorporating environmental factors into their models and found that country-specific environmental conditions exert a strong influence on the behavior of banks.

In making comparisons of banking efficiency across countries, we need to estimate a common frontier for all banks in these countries under consideration. It is important to simultaneously consider country-specific environmental conditions, which influence the level of efficiency for all banks. If we simply pool all banks across countries without regard to the impact of the environmental differences, we are implicitly assuming that efficiency differences across countries are entirely ascribable to managerial ability of banks. Biased estimates may result. Therefore, we adopt a meta-cost frontier function, proposed by Battese et al. (2004), to estimate bank efficiency across countries. This function allows for the calculation of technical efficiencies for banks operating under different technologies.

2.2 Meta-frontier model

Hayami (1969) first proposed the meta-frontier production function to examine the causes of agricultural productivity differences among the developed and less developed countries, followed by Hayami and Ruttan (1970, 1971). Hayami and Ruttan (1970, 1971) made a crucial assumption that the technological possibilities available to all agricultural producers in different countries under consideration can be characterized by the same production function, namely the meta-production function. This concept is theoretically attractive, because it is based on the simple hypothesis that all producers in different countries have potential access to the same technology, and it allows for the comparisons of production efficiencies among producers operating under different technologies. However, one may notice that the meta-production function does not imply that all producers operate on a universal production function. The meta-production function, proposed by Ruttan et al. (1978), is an envelope curve of production points of the most efficient countries. Each country may choose to operate on different part of the production possibility curve, depending on its resource endowments, adoption and diffusion of technology, and economic environments.

Following the seminal work of Hayami and Ruttan (1970, 1971), Lau and Yotopoulos (1989) employed the meta-production function approach to compare agricultural productivity across countries. They addressed some econometric advantages of applying the meta-production function. This approach is particularly able to pool data from different countries to estimate a common production function, thus increasing the range of variation of the independent variables and the number of observations. Moreover, it reduces the possibility of multicollinearity among inputs, as various inputs are usually changing together. Consequently, more precise and reliable parameters estimates may be obtained. Several limitations inherent to this approach are worth mentioning. The non-comparability of data, the differences in the basic economic environments and the specification of an appropriate production function pose some difficulties.

Sharma and Leung (2000) and Gunaratne and Leung (2001) further adopted a stochastic meta-frontier model. The setting is exactly the same as the standard stochastic frontier approach (SFA), originally proposed by Aigner, Lovell, and Schmidt (1977). Sharma and Leung (2000) studied the technical efficiency of aquaculture farms in several South-Asian countries, using the model developed by Battese and Coelli (1995) under the framework of the stochastic meta-frontier function, where the effects of various firm-specific variables on technical efficiency were simultaneously investigated.

Battese and Rao (2002) attempted to compare the technical efficiencies of firms in different groups that may not have the same technology on the basis of the stochastic meta-frontier production function. They assumed that there are two different data-generation mechanisms for the data, one with respect to the stochastic frontier that is estimated using data belonging to that group, and the other with respect to the meta-frontier model that is estimated using entire sample data. The estimation of the technology gap helps us identify the ability of the firms in one group to compete with other firms from different groups within an industry. Following Battese and Rao (2002), Battese, Rao, and O'donnell (2004) modified the above model by assuming that data-generation processes are only applied for the frontier models for the firms in the different groups. Meanwhile, the meta-frontier function is an overarching function of a given mathematical form that envelopes the deterministic components of the stochastic frontier production functions for the firms that operate under different technologies involved.

3. Methodology

In this chapter, we present the methodology to be used to estimate cost efficiency, technology gap, scale economies, and scope economies. As discussed by Berger and Mester (1997), the adoption of the economic efficiency concepts will provide further insights into the problem of the economic optimization.[3] The cost efficiency is undoubtedly an appropriate approach since the European financial markets have been more competitive and highly integrated. The main idea comes from Battese et al. (2004) while generalized to a cost frontier setting.

3.1 Stochastic Meta-frontier Cost Function

Cost efficiency is gauged by the extent to which a bank's actual cost deviates from the efficient cost frontier. We first introduce the stochastic cost frontiers of the banking industry for each country. Suppose that there are R different countries under consideration, and that each country k has N_k banks that face input prices and seek to minimize the cost which they incur in producing the outputs. The stochastic cost frontier model for each bank w of country k at time t can be given as

$$\begin{aligned} &C_{wt(k)} = f(X_{wt(k)}, \varphi_{(k)}) e^{V_{wt(k)} + U_{wt(k)}}, \\ &w = 1,2,\ldots,N_k; t = 1,2,\ldots,T; k = 1,2,\ldots,R, \end{aligned} \tag{1}$$

where $C_{wt(k)}$ is the total expenditure, $X_{wt(k)}$ is a vector of outputs and input prices, $\varphi_{(k)}$ is the unknown technology parameter vector to be estimated. $V_{wt(k)}$ and $U_{wt(k)}$ are identically and independently distributed random variables. The former is assumed to be distributed as N(0 , $\sigma^2_{v(k)}$), capturing the statistical noise, and the latter is assumed to be a truncated normal distribution, a positive disturbance capturing technical inefficiency, to be specified shortly. For expository convenience, equation (1) is further formulated as

$$C_{wt(k)} = e^{X_{wt(k)}\varphi_{(k)} + V_{wt(k)} + U_{wt(k)}} \tag{2}$$

The model, as proposed by Battese et al. (2004), assumes that there is only one

[3] There are three economic concepts: cost, revenue and profit efficiencies.

data-generation process for the banks operating under a given technology for each country. The data is individually generated from the frontier models in the different countries. In general, the meta-frontier is assumed to have the same functional form as the stochastic frontiers in the different countries. Thus, the meta-frontier cost function for all banks is given by

$$C^*_{wt} = f(X_{wt}, \varphi^*) \equiv e^{X_{wt}\varphi^*},$$
$$w = 1,2,..., N = \sum_{k=1}^{R} N_k ; t = 1,2,..., T \tag{3}$$

where C^*_{wt} is the minimum expenditure incurred by the bank w in year t; φ^* is the corresponding parameter vector associated with the meta-frontier cost function such that

$$X_{wt}\varphi^* \le X_{wt}\varphi_{(k)} \tag{4}$$

The meta-frontier is defined as a deterministic parametric function such that its values must be less than or equal to the deterministic components of the stochastic cost frontier of the different countries involved. The inequality constraint of equation (4) is held for all countries and time periods. The meta-frontier is considered to be an envelope of the individual stochastic frontiers of the different countries. Figure 1 provides an illustration of how the meta-frontier envelopes the stochastic frontiers of the different countries. We will estimate the stochastic cost frontiers for each country, denoted by frontier1, frontier2 and frontier3 in the figure. Then, a meta-frontier is estimated as an envelope curve which surrounds the three stochastic frontiers from below using the pooled data over all countries.

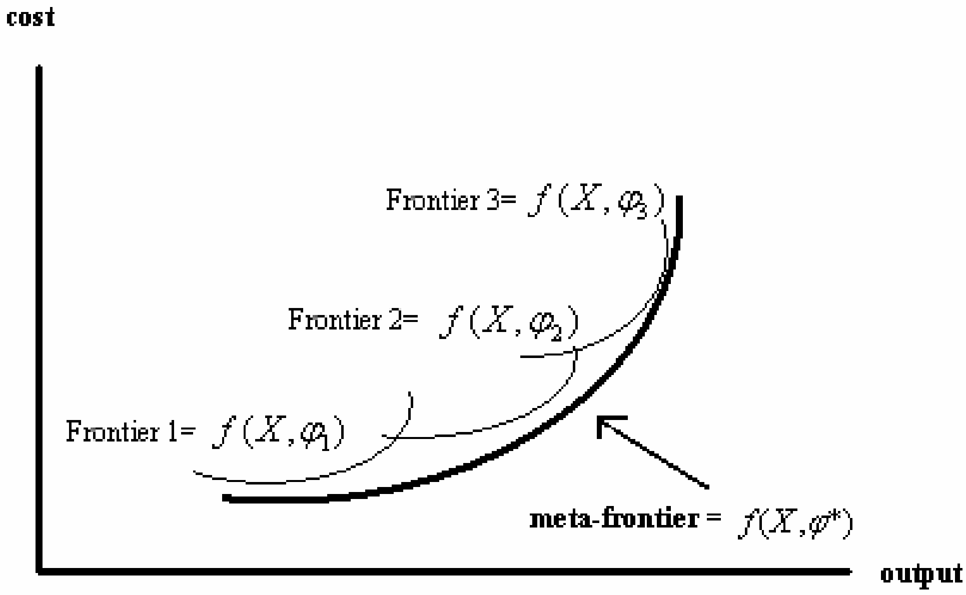


Figure 1. Meta-frontier Model

3.2 Technology Gap and Efficiency Levels

Cost efficiency is determined by how close a bank's cost lie to the overall cost frontier, namely the meta-frontier. Therefore, the measure of cost efficiency (CE*) for bank w in year t is formulated by the ratio of the minimum cost to observed cost, adjusted by the corresponding random error,

$$CE^*_{wt(k)} = \frac{e^{X_{wt}\varphi^* + V_{wt(k)}}}{C_{wt(k)}} \tag{5}$$

Substituting (2) into (5), we obtain

$$CE^*_{wt(k)} = \frac{e^{X_{wt}\varphi^* + V_{wt(k)}}}{e^{X_{wt}\varphi_{(k)} + V_{wt(k)} + U_{wt(k)}}} = e^{-U_{wt(k)}} \times \frac{e^{X_{wt}\varphi^*}}{e^{X_{wt}\varphi_{(k)}}} \tag{6}$$

where the first term on the right-hand side of equation (6) is the conventional technical efficiency (CE) relative to the stochastic frontier of country k,

$$CE_{wt(k)} = \frac{e^{X_{wt}\varphi_{(k)} + V_{wt(k)}}}{e^{X_{wt}\varphi_{(k)} + V_{wt(k)} + U_{wt(k)}}} = e^{-U_{wt(k)}} \tag{7}$$

It must lie between zero and one, because U_{wt} is a nonnegative random variable by construction. The second term on the right-hand side of equation (6) is the technology gap ratio (TGR), i.e.

$$TGR_{wt(k)} = \frac{e^{X_{wt}\varphi^*}}{e^{X_{wt}\varphi_{(k)}}} \tag{8}$$

The TGR mainly evaluates the degree of technology gap for country k whose currently available technology adopted by its banks lags behind the technology available for all countries. We measure the TGR using the ratio of the potential cost that is defined by the meta-frontier function to the cost for the frontier function for country k given the observed outputs and input prices. It has a value between zero and one because of equation (4).

The cost efficiency measure of equation (5) can be expressed as

$$CE^*_{wt(k)} = CE_{wt(k)} \times TGR_{wt(k)} \tag{9}$$

CE* also lies between zero and one because CE and TGR are both between zero and one.

3.3 Formula of the Scale and Scope Economies

In the context of multiple outputs, a formal measure of scale economies is referred to as ray scale economies (RSE), developed by Baumol et al. (1982) and applied to banking by Berger et al. (1987). It is defined as

$$RSE = \sum_i \frac{\partial \ln f}{\partial \ln y_i} \tag{10}$$

where y_i is the ith output produced by a bank and f is its cost function. An estimate of RSE less than, equal to, or greater than 1 indicates, respectively, scale economies, constant returns to scale, or scale diseconomies.

Economies of scope exists when total cost of a firm simultaneously producing more than one output are lower than the sum of the costs of firms producing each output separately. In the case of a bank producing two outputs, as suggested by

Mester (1996), the estimate of scope economies is defined as

$$SC=\frac{\left[f(y_1-y_1^m,y_2^m)+f(y_1^m,y_2-y_2^m)-f(y_1,y_2)\right]}{f(y_1,y_2)} \tag{11}$$

where y_i^m is 10% of the minimum value of y_i in the sample. The purpose of using y_i^m, instead of zero in the equation, avoids taking the logarithms of zero in the translog function. An estimate of SC greater than, or less than zero indicates, respectively, scope economies or scope diseconomies.

3.4 Estimation Procedure

Now that we have introduced the meta-frontier model, the next step is to estimate the technology parameters of the cost function. The estimation procedure is divided into three steps:

1. Obtain the maximum likelihood estimates, $\hat{\varphi}_{(k)}$, of $\varphi_{(k)}$ in the stochastic cost frontier for country k. The stochastic frontier model proposed by Battese and Coelli (1992), which allows for time-varying technical efficiency, will be adopted.
2. Obtain the estimate of $\varphi*$ in the meta-frontier. Battese et al. (2004) pointed out that there are two approaches to find out the best envelop curve. Detailed see below.
3. According to equations (6)-(11), calculate the cost efficiency, the technology gap, scale economies ,and scope economies, using $\hat{\varphi}_{(k)}$ and $\hat{\varphi}*$ obtained by Step 1 and 2.

We now return to the estimation procedure on the meta-frontier. There are two alternative approaches can be applied to identify the best meta-frontier. One is based on the sum of absolute deviations of the meta-frontier values from those of the group frontiers, and the other is based on the sum of squares of the same deviations.

I. Minimum sum of absolute deviations

$\hat{\varphi}*$ is estimated by solving the optimization problem:

$$\min L* \equiv \sum_{t=1}^{T}\sum_{w=1}^{N}\left|\ln f(X_{wt},\hat{\varphi}_{(k)})-\ln f(X_{wt},\varphi*)\right| \quad (12)$$

$$s.t. \ln f(X_{wt},\varphi*) \le \ln f(X_{wt},\hat{\varphi}_{(k)}) \quad (13)$$

It will be clear from equation (12) and (13) that the estimated meta-frontier minimizes the sum of absolute logarithms of $f(X_{wt},\hat{\varphi}_{(k)})/f(X_{wt},\varphi*)$, which represents the reciprocal of the radial distance between the meta-frontier and the frontier of country k. The weights of the deviations for all banks in the sample are the same. One may notice that all the deviations are positive because of equation (13). Therefore, all the absolute deviations are exactly equal to the differences. Using equations (2) and (3), we can simplify the above optimization problem to the linear programming (LP) problem:

$$\min L* \equiv \sum_{t=1}^{T}\sum_{w=1}^{N}\left(X_{wt}\hat{\varphi}_{(k)}-X_{wt}\varphi*\right) \quad (14)$$

$$s.t. X_{wt}\varphi* \le X_{wt}\hat{\varphi}_{(k)} \quad (15)$$

II. Minimum sum of squares of deviations:

The other approach minimizes the sum of squares of the deviations between the meta-frontier and the frontier of the individual countries. $\hat{\varphi}*$ is estimated by solving a quadratic programming (QP) problem:

$$\min L** \equiv \sum_{t=1}^{T}\sum_{w=1}^{N}\left(X_{wt}\hat{\varphi}_{wt}-X_{wt}\varphi*\right)^2 \quad (16)$$

$$s.t. X_{wt}\varphi* \le X_{wt}\hat{\varphi}_{(k)}$$

What is immediately apparent in this equation is that the larger the technology gap ratio of the bank is, the higher weight to the deviation is.

Standard errors of the estimators for the two meta-frontier can be obtained by either simulation or bootstrapping methods. Bootstrapping method will be used in this paper.

4. Data Source and Variable Definition

The primary data source is from the *Bankscope* database over the period 1994-2003 and supplemented with the *Eurostat* database and *Taiwan Statistical Data Book*. We use unconsolidated accounting data for 828 banks in 16 European countries. We only include those banks with at least three years of available data. The total number of observations is 4,977. Besides, all the nominal variables have been transformed into real terms by the consumer price index of individual countries with base year 1985.

We employ the intermediation approach to define inputs and outputs. Specifically, three output categories are identified as: loans, investments, and non-interest revenues. The inputs include labor, physical capital, and borrowed funds. As data on the number of employees are not available from the databank, the price of labor is defined as the ratio of personnel expenses to total assets. Altunbas et al.(2000, 2001) and Weill(2004) employed the same definition. The price of physical capital is defined as the ratio of other non-interest expenses to fixed assets. The price of borrowed funds is measured by the ratio of paid interests to all funding. Total costs are the sum of the above three items of expenditure. Table 1 summarizes descriptive statistics and the distributions of the sample banks among countries. These statistics indicate that there are considerable differences among the countries.

Table 1 : Descriptive statistics of dataset - country average.

Variable	Austria	Belgium	Denmark	Finland	France	Germany	Greece	Italy	Luxembourg	Netherlands	Norway	Portugal	Spain	Sweden	Switzerland	UK
Total number of banks	21	24	48	10	156	141	18	121	63	13	12	22	58	11	94	16
Total number of observations	137	118	339	48	907	861	121	766	328	94	78	134	361	57	540	88
Total cost	342.0152	770.6157	173.9057	540.3178	624.560138	599.6001	111.5377	441.1900	483.0223	330.7489	363.9005	221.4476	314.8106	870.5152	495.3035	267.3878
	(738.4505)	(1,527.2528)	(525.9168)	(591.5974)	(2,019.2870)	(2,520.6303)	(170.1370)	(1,118.1825)	(592.3419)	(802.8914)	(441.3191)	(298.1052)	(771.0827)	(936.1710)	(2,423.9160)	(635.8698)
Outputs																
Total loans	5752.4089	2870.8298	2476.7888	9512.3615	6536.228037	8575.3611	932.4758	5136.0296	4994.3971	5266.0078	5491.6551	2173.0419	4000.3145	12354.5979	7061.7418	234.6226
	(11,817.7299)	(6,336.7061)	(7,901.5202)	(12,215.2397)	(21,244.2365)	(35,518.4875)	(1,326.9539)	(12,775.2779)	(5,850.4115)	(13,110.8512)	(6,791.2679)	(2,897.7409)	(9,249.4752)	(14,162.7842)	(34,367.5024)	(607.2661)
Total investments	1176.8494	4009.7393	1063.2057	3014.8806	2493.294664	2886.8931	468.0788	1275.4837	2561.5475	723.7700	850.0509	506.1777	1282.3567	4068.7148	2380.9333	985.6606
	(2,678.0225)	(7,776.7153)	(3,947.6852)	(2,954.6339)	(9,530.0935)	(15,369.2916)	(869.8046)	(3,133.7969)	(3,350.8017)	(1,778.5995)	(1,084.5914)	(750.3299)	(4,193.6309)	(4,594.5287)	(14,130.3583)	(2,467.2828)
Non-interest revenue	34.9115	590.3803	39.9994	98.5514	129.1542	121.3604	10.0389	97.6324	47.2918	3.2005	73.3750	110.3945	59.8490	162.9436	167.8554	58.9706
	(57.2138)	(1,202.2564)	(140.0078)	(116.0593)	(527.2182)	(614.4434)	(18.1087)	(227.8687)	(63.4064)	(3.5646)	(95.1664)	(219.4341)	(133.7706)	(159.1530)	(765.6894)	(129.6807)
Input prices (in %)																
Price of labor	1.4011	1.2963	2.0038	1.0650	1.714248	1.3801	1.8914	1.7582	0.3979	0.7182	0.8862	1.1653	1.5795	1.1866	1.7933	1.0515
	(0.8282)	(0.8605)	(0.8776)	(2.0078)	(1.2502)	(0.9748)	(0.8420)	(1.0022)	(0.3535)	(1.1477)	(0.2894)	(0.6026)	(1.2323)	(0.5498)	(1.7058)	(0.6443)
Price of borrowed funds	3.2372	3.9565	2.8996	3.3125	4.867901	4.6322	6.8057	4.1564	6.8547	5.2390	5.1917	6.1672	4.4500	3.2297	3.1456	4.8291
	(0.9282)	(1.0610)	(1.0293)	(1.3383)	(6.0149)	(12.8035)	(3.1665)	(2.8922)	(4.6839)	(2.5897)	(1.2886)	(6.4276)	(8.2275)	(1.6809)	(1.7131)	(2.7948)
Price of physical capital	87.3138	568.4903	154.9729	330.4598	400.932894	294.8965	114.5686	138.7337	33.6720	219.2871	114.4839	103.0388	99.2069	744.7346	233.7107	236.3665
	(76.7428)	(694.4088)	(272.9975)	(444.7610)	(578.3759)	(425.2311)	(63.2373)	(212.8516)	(34.8736)	(202.5505)	(372.0884)	(99.7869)	(149.4540)	(855.0085)	(492.3772)	(315.3139)

Note: All values are in millions dollars, except where indicated. Standard deviations are in parenthesis.

5. Empirical Results

5.1 Parameter Estimates

Each country's cost frontier is estimated by the model developed by Battese and Coelli (1992). A standard translog cost function with trends is expressed as

$$\ln C_{wt} = \alpha_0 + \sum_{j=1}^{4}\alpha_j \ln Y_{jwt} + \sum_{k=1}^{3}\beta_k \ln W_{kwt} + \frac{1}{2}\sum_{j=1}^{4}\sum_{m=1}^{4}\gamma_{jm}\ln Y_{jwt}\ln Y_{mwt}$$

$$+\frac{1}{2}\sum_{k=1}^{3}\sum_{n=1}^{3}\delta_{kn}\ln W_{kwt}\ln W_{nwt} + \sum_{j=1}^{4}\sum_{k=1}^{3}\rho_{jk}\ln Y_{jwt}\ln W_{kwt} + U_{wt} + V_{wt} \quad (17)$$

where U_{wt} denotes the production inefficiency and is further specified as

$$U_{wt} = \{\exp[-\eta(t-T)]\}U_w. \quad (18)$$

C_{wt} is the real total costs for the bank w at time t, Y_1 is the loans, Y_2 is the investments, Y_3 is the non-interest revenues, Y_4 is the linear time trend, W_1 is the price of labor, W_2 is the price of physical capital, W_3 is the price of borrowed funds, V_{wt} is identically and independently distributed normal random variables with mean zero and constant variance $\sigma^2{}_v$, and U_w is assumed to be a truncated normal distribution as $N^+(\mu, \sigma_u^2)$. Both V_{wt} and U_w are mutually independent.

There are a few characteristics deserving specific mention. Microeconomic theory requires that a cost function must have some properties. For example, a cost function is homogeneous of first degree in input prices; it is symmetrical, i.e., $\gamma_{jm} = \gamma_{mj}$ (for all $j \neq m$) and $\delta_{kn} = \delta_{nk}$ (for all $k \neq n$). Other properties can be checked after the parameters have been estimated. For estimation convenience, we transform equation (17) into

$$\ln C_{wt}^{*} = \alpha_0 + \sum_{j=1}^{4} \alpha_j \ln Y_{jwt} + \sum_{k=2}^{3} \beta_k \ln W_{kwt}^{*} + \frac{1}{2} \sum_{j=1}^{4} \sum_{m=1}^{4} \gamma_{jm} \ln Y_{jwt} \ln Y_{mwt}$$
$$+ \frac{1}{2} \sum_{k=2}^{3} \sum_{n=2}^{3} \delta_{kn} \ln W_{kwt}^{*} \ln W_{nwt}^{*} + \sum_{j=1}^{4} \sum_{k=2}^{3} \rho_{jk} \ln Y_{jwt} \ln W_{kwt}^{*} + U_{wt} + V_{wt} \quad (19)$$

where $\ln C_{wt}^{*} = \ln C_{wt} - \ln W_{1wt}$, $\ln W_{kwt}^{*} = \ln W_{kwt} - \ln W_{1wt}$, $k = 2,3$, and $\ln W_{nwt}^{*}$ is similarly defined. In other words, the first input is arbitrarily chosen as the numeraire and its price is used to normalize all the terms involving C, W_2, and W_3. Thus, the α , β , γ , δ , ρ ,η,μ,σ^2_v and σ_u^2 are unknown parameters to be estimated. Table 2 reports estimation results of each country based on equation (19) using the FRONTIER 4.1 program (Coelli, 1996).

The translog cost function is known as flexible, in the sense that it provides a second-order approximation to the true function. Taking these estimated parameters as given, we can examine whether the estimated cost function is concave in input prices. Particularly, the Hessian matrix requires $H_1 \le 0$, $H_2 \ge 0$, and $H_3 \le 0$, where the Hessian matrices are defined as

$$H_1 = \left| C_{11}^{*} \right| \le 0 \text{，} H_2 = \begin{vmatrix} C_{11}^{*} & C_{12}^{*} \\ C_{21}^{*} & C_{22}^{*} \end{vmatrix} \ge 0 \text{，} H_3 = \begin{vmatrix} C_{11}^{*} & C_{12}^{*} & C_{13}^{*} \\ C_{21}^{*} & C_{22}^{*} & C_{23}^{*} \\ C_{31}^{*} & C_{32}^{*} & C_{33}^{*} \end{vmatrix} \le 0 \quad (20)$$

where $C_{kn}^{*} = \dfrac{\partial^2 C}{\partial W_k \partial W_n}, \forall k, n = 1,2,3$.

Next, according Shephard's Lemma, an input share is equal to the derivative of the log cost function with respect to that log input price. Each input share should lie in zero and unity, and adds up to 1, i.e.,

$$0 < S_k = \frac{\partial \ln C}{\partial \ln W_k} < 1, k = 1,2,3, \text{ and } \sum_{k=1}^{3} S_k = 1. \quad (21)$$

Finally, the marginal cost should be positive, i.e.,

$$MC_j = \frac{\partial C}{\partial Y_j} > 0 \text{，} j = 1,2,3 \tag{22}$$

Table 3 summarizes the above calculations based on equations (20) through (22). It reports the number of sample points inconsistent with the theory. Most of the observations satisfy the stated properties, although there are some observations against the requirements. In their recent survey on the estimation of the cost function, Greene et al. (2004) have given some explanations for this problem. It may come from that the share equations are not simultaneously estimated. However, the translog cost function is largely congruent with the theory and hence well-representative.

Having estimated and analyzed each country's cost frontier, one may ask whether all countries' banks are operating under a unique type of technology or not. If all banks share the same technology, it would be unnecessary to analyze data by a meta-frontier model. A likelihood-ratio (LR) test of the null hypothesis that all countries' stochastic cost frontiers are the same is performed. We compare the sum of the values of the log-likelihood functions for the stochastic cost frontiers for sixteen countries with the value of the log-likelihood function for the stochastic cost frontier estimated by pooling all the data. The value of the LR statistic amounts to 2295. The null hypothesis is strongly rejected.[4] Now that we are sure that each country's banks operate under different technology, the next step is to calculate a meta-frontier function.

In order to compare the meta-frontier function with the conventional studies, where the banking efficiencies are evaluated by simply pooling all the data across countries without considering the technical difference, we also estimate the translog

[4] The degrees of freedom of the LR statistic's Chi-square distribution are 480, the difference between the number of parameters estimated under the null hypothesis and the alternative hypothesis.

Table 2 : Estimation results of stochastic cost frontier

Variable	Austria	Belgium	Denmark	Finland	France	Germany	Greece	Italy
Constant	4.6911 ***	8.0493 ***	1.7342 ***	-3.5158	2.0856 ***	4.0476 ***	2.1017 **	2.3869 ***
	(5.1555)	(7.1754)	(2.6935)	(-1.1361)	(3.9513)	(10.1633)	(2.0174)	(4.1141)
Loans	-0.3818	-0.4183 *	0.8486 ***	0.1633	0.3657 **	0.1257	0.3836	0.5182 ***
	(-1.1575)	(-1.6885)	(3.7977)	(0.4021)	(2.5289)	(1.0874)	(0.5345)	(3.0715)
Investments	0.5075 **	-0.5613 *	0.0975	0.4539	-0.1178	0.0321	0.2767	0.0153
	(2.2870)	(-1.8291)	(0.6194)	(0.9798)	(-1.6207)	(0.3933)	(0.3659)	(0.1265)
Non-interest revenues	0.4017 *	1.0674 **	-0.0677	0.2901	0.5841 ***	0.4670 ***	0.3609	0.3629 ***
	(1.8382)	(2.3806)	(-0.4391)	(0.5052)	(6.3832)	(5.0176)	(0.5714)	(3.0518)
Price of physical capital / Price of labor	0.4333	0.9607 **	0.1234	2.1243 **	0.2821 **	0.1141	4.7546 ***	0.7332 ***
	(0.7744)	(2.4674)	(0.4660)	(2.9184)	(2.2968)	(0.7264)	(4.0900)	(4.0883)
Price of borrowed funds / Price of labor	0.1577	-0.7687 ***	0.5035 ***	0.9271 *	0.3845 ***	0.2133 **	-1.4797 *	-0.2061
	(0.5620)	(-2.7322)	(3.1388)	(1.8777)	(3.9904)	(2.2156)	(-1.8061)	(-1.4183)
year	-0.2294 **	0.0733	-0.1584 ***	0.4565 *	0.0864	-0.2848 ***	0.3129	0.2172 ***
	(-2.2442)	(0.8698)	(-2.7060)	(2.0025)	(1.3561)	(-6.5287)	(1.1764)	(3.5603)
$(\text{Loans})^2$	0.0058	0.1040 ***	-0.1437 ***	0.4335 **	0.0490 *	0.1523 ***	-0.1663	-0.0340
	(0.0532)	(5.9909)	(-3.0498)	(2.4644)	(1.8788)	(5.4574)	(-0.8294)	(-1.2628)
$(\text{Investments})^2$	-0.0460	0.1012 *	0.0575	0.3643	-0.0201 **	0.0251	-0.0316	0.0061
	(-0.7781)	(1.6910)	(1.3039)	(1.3804)	(-2.0722)	(1.1960)	(-0.2445)	(0.3096)
$(\text{Non-interest revenues})^2$	-0.1448 **	-0.2226 **	0.0479 ***	0.3300 ***	0.0655 ***	0.0336 ***	-0.1332 *	0.0447 ***
	(-2.1189)	(-2.3275)	(5.7822)	(3.2488)	(10.6256)	(7.3904)	(-1.6628)	(7.3265)

Note: t-statistics are given in parenthesis and *** denotes statistical significance at the 1%, ** at the 5% and * at the 10 %

Table 2 : Estimation results of stochastic cost frontier (continued)

Variable	Austria	Belgium	Denmark	Finland	France	Germany	Greece	Italy
(Price of physical capital / Price of labor)^2	-0.3262 **	-0.2361 **	0.0857	0.2845 *	-0.0108	-0.4468 ***	-0.4384	0.0094
	(-2.0617)	(-2.4055)	(1.0773)	(2.0377)	(-0.4423)	(-10.1538)	(-0.6378)	(0.2031)
(Price of borrowed funds / Price of labor)^2	-0.0259	0.0635	-0.0900 ***	0.1317	0.0035	0.0618 ***	0.1702	0.1202 ***
	(-0.4527)	(1.4255)	(-2.5998)	(1.6067)	(0.2223)	(2.6616)	(0.7393)	(4.1351)
year^2	0.0177 **	0.0122	0.0244 ***	0.0321	-0.0035	0.0183 ***	0.0400	0.0165 ***
	(2.0272)	(1.6047)	(4.1473)	(1.5804)	(-0.5070)	(3.6885)	(1.2897)	(2.7543)
(Loans) × (Investments)	0.0135	-0.0735 **	-0.0012	-0.3271	0.0266 **	-0.0647 ***	0.0695	0.0048
	(0.2203)	(-2.1065)	(-0.0338)	(-1.6500)	(2.2301)	(-3.2568)	(0.5099)	(0.2568)
(Investments) × (Non-interest revenues)	0.0542	0.1180 *	-0.0436	-0.0029	-0.0183 *	0.0213	0.0472	-0.0226 *
	(1.0161)	(1.6903)	(-1.4490)	(-0.0314)	(-1.8275)	(1.4939)	(0.6018)	(-1.7099)
(Loans) × (Non-interest revenues)	0.0539	0.0225	0.0996 ***	-0.1609	-0.0306 **	-0.0374 ***	0.0449	0.0502 ***
	(0.6345)	(0.6375)	(3.3959)	(-1.6488)	(-2.2836)	(-2.1820)	(0.3948)	(2.9423)
(Price of physical capital / Price of labor)	0.1141 *	0.1699 ***	0.1134 ***	-0.0917	0.0529 ***	0.0810 ***	-0.2500	-0.0058
× (Price of borrowed funds / Price of labor)	(1.6817)	(3.0626)	(2.7782)	(-0.7541)	(2.9833)	(2.8135)	(-0.7816)	(-0.2067)
(Loans)	0.2060 *	-0.2320 ***	0.0539	-0.0859	0.0301	0.2690 ***	-0.4502 **	0.0936 ***
× (Price of physical capital / Price of labor)	(1.8345)	(-5.2487)	(1.0259)	(-0.6863)	(1.5515)	(8.6084)	(-1.9898)	(2.8695)
(Loans)	0.0386	0.0929 ***	0.0100	-0.1445 *	-0.0591 ***	-0.1573 ***	0.3302 **	-0.0609 **
× (Price of borrowed funds / Price of labor)	(0.6081)	(2.7893)	(0.3131)	(-1.9529)	(-3.6829)	(-7.8183)	(2.0787)	(-2.2807)
(Investments)	-0.1426 *	-0.0696	-0.0352	-0.0792	0.0386 ***	0.0147	0.2572	-0.0133
× (Price of physical capital / Price of labor)	(-1.8147)	(-1.4156)	(-0.7371)	(-0.4852)	(2.7580)	(0.5436)	(1.2759)	(-0.6075)
(Investments)	-0.0359	0.0356	-0.0447	0.0165	0.0008	0.0523 ***	-0.1930	0.0244
× (Price of borrowed funds / Price of labor)	(-0.7945)	(1.1401)	(-1.6259)	(0.2139)	(0.0826)	(3.1285)	(-1.2306)	(1.1863)

Note: t-statistics are given in parenthesis and *** denotes statistical significance at the 1%, ** at the 5% and * at the 10 %

Table 2 : Estimation results of stochastic cost frontier (continued)

Variable	Austria	Belgium	Denmark	Finland	France	Germany	Greece	Italy
(Non-interest revenues)	-0.0026	0.2439 ***	0.0345	0.1279	-0.0270 *	-0.2363 ***	0.1506	-0.1468 ***
× (Price of physical capital / Price of labor)	(-0.0311)	(3.9371)	(0.8207)	(1.4518)	(-1.9570)	(-11.6245)	(1.0357)	(-6.1573)
(Non-interest revenues)	-0.0737	-0.1296 **	0.0175	0.0722	-0.0079	0.0778 ***	-0.1721	-0.0057
× (Price of borrowed funds / Price of labor)	(-1.3415)	(-2.6216)	(0.6343)	(0.8060)	(-0.6430)	(4.4683)	(-1.6402)	(-0.2909)
Loans × year	0.0180	0.0033	0.0015	0.0936 **	-0.0097	0.0497 ***	-0.0443	-0.0147
	(1.1360)	(0.3919)	(0.1212)	(2.7511)	(-1.4120)	(6.5697)	(-0.7813)	(-1.1998)
Investments × year	0.0176	-0.0424 ***	-0.0083	-0.0537	0.0033	0.0022	-0.0013	-0.0011
	(1.2517)	(-2.9017)	(-0.8425)	(-1.4741)	(0.7901)	(0.3906)	(-0.0300)	(-0.1235)
Non-interest revenues × year	-0.0075	0.0481 **	0.0057	-0.0737 *	0.0103 *	-0.0375 ***	0.0299	-0.0029
	(-0.5868)	(2.4815)	(0.5159)	(-1.9282)	(1.6788)	(-6.3195)	(0.8048)	(-0.2912)
(Price of physical capital / Price of labor) × year	-0.0560 ***	-0.0476 **	-0.0192	-0.0723	-0.0031	-0.0599 ***	-0.1258	0.0154
	(-2.7661)	(-2.0949)	(-1.5797)	(-1.3135)	(-0.3987)	(-6.5833)	(-1.0129)	(1.2468)
(Price of borrowed funds / Price of labor) × year	0.0052	-0.0025	0.0087	-0.0760 **	0.0110 *	0.0081	0.0100	-0.0128
	(0.2785)	(-0.2362)	(0.9238)	(-2.1603)	(1.8498)	(1.5290)	(0.1508)	(-1.2050)
σ_v^2	0.0557 ***	0.0514 ***	0.0826 ***	0.0545 ***	0.1557 ***	0.1599 ***	0.2266 ***	0.1513 ***
	(5.5606)	(6.4338)	(11.8471)	(4.6998)	(20.5056)	(13.8957)	(10.3453)	(81.5439)
$\sigma_u^2/(\sigma_v^2+\sigma_u^2)$	0.3724 *	0.6621 ***	0.6870 ***	0.8233 ***	0.0047 ***	0.2168 ***	0.4174 ***	0.1869 ***
	(1.6996)	(4.8604)	(10.0840)	(14.0944)	(8.3325)	(4.3471)	(970.0990)	(17.7421)
μ	0.2880 *	0.3690 ***	0.4766 ***	0.4237 *	0.0539 ***	-0.3724	0.6151 **	0.3362 ***
	(1.9091)	(3.1433)	(4.0461)	(1.9914)	(3.6358)	(-1.4150)	(2.4735)	(8.6480)
η	-0.0229	0.0075	-0.0241	0.1255 ***	0.3225 ***	0.2423 ***	-0.0652	0.1005 ***
	(-0.5243)	(0.3121)	(-1.2735)	(4.7485)	(11.8477)	(4.0720)	(-0.9607)	(14.2992)

Note: t-statistics are given in parenthesis and *** denotes statistical significance at the 1%, ** at the 5% and * at the 10 %

Table 2 : Estimation results of stochastic cost frontier (continued)

Variable	Luxembourg	Netherlands	Norway	Portugal	Spain	Sweden	Switzerland	UK
Constant	-0.3137	3.4792	4.2856 ***	9.9192 ***	1.9041 **	6.9389 ***	3.0915 ***	2.8992 ***
	(-0.2534)	(1.4924)	(4.3305)	(4.2598)	(2.2842)	(6.2917)	(5.7673)	(3.0302)
Loans	0.6638 **	-0.8638	0.7635	-0.5521	0.6905 **	-2.4991 ***	-0.5762 ***	-0.9798 **
	(1.9794)	(-1.3912)	(0.9275)	(-1.1185)	(2.4988)	(-5.9207)	(-3.4269)	(-2.4929)
Investments	0.4162 ***	0.6628	-0.9930	0.4057	-0.1457	1.9162 ***	0.6201 ***	0.4172 **
	(2.8785)	(1.4322)	(-1.0800)	(1.0582)	(-0.8510)	(4.1821)	(4.9198)	(2.2820)
Non-interest revenues	-0.0019	0.5239	0.7594	0.4488	0.4145 *	1.7386 ***	0.6055 ***	1.2579 ***
	(-0.0076)	(1.2554)	(0.7859)	(1.2737)	(1.8975)	(5.0654)	(4.4968)	(5.1755)
Price of physical capital / Price of labor	2.3012 ***	1.1750 *	0.9072	-0.7470	1.1481 ***	1.3451 ***	0.4201 **	2.2540 ***
	(7.9666)	(1.9161)	(0.9177)	(-1.2167)	(3.6249)	(3.0161)	(2.4163)	(6.0780)
Price of borrowed funds / Price of labor	0.0623	0.3116	-0.3010	-0.9110	0.0622	-0.0359	0.3214 ***	-0.2152
	(0.2710)	(0.4513)	(-0.3151)	(-1.2625)	(0.2515)	(-0.1489)	(2.8902)	(-0.9489)
year	-0.0872	0.3484 **	-0.2111	-0.7304 ***	0.1431	-0.3727 ***	-0.0798	0.2289
	(-1.1991)	(2.1851)	(-0.2287)	(-3.3946)	(0.9847)	(-3.0508)	(-1.4350)	(1.4928)
$(\text{Loans})^2$	-0.0177	0.1794 *	0.0063	-0.0485	-0.0852	0.5755 ***	0.2247 ***	-0.0269
	(-0.2482)	(1.7176)	(0.0093)	(-0.6052)	(-1.3763)	(6.4692)	(7.5384)	(-0.4443)
$(\text{Investments})^2$	0.0392 **	0.0855	0.9509	0.0232	0.0342	-0.0737	0.0256	0.1853 ***
	(2.2065)	(0.9126)	(1.1411)	(0.3042)	(1.2916)	(-0.8147)	(0.9851)	(4.2993)
$(\text{Non-interest revenues})^2$	0.0821	0.0172	0.4786	0.0057	0.0143	-0.2763 ***	0.0327 ***	0.3049 ***
	(0.0917)	(0.8440)	(0.6188)	(0.0691)	(0.2940)	(-3.0021)	(6.0316)	(5.8721)

Note: t-statistics are given in parenthesis and *** denotes statistical significance at the 1%, ** at the 5% and * at the 10 %

Table 2 : Estimation results of stochastic cost frontier (continued)

Variable	Luxembourg	Netherlands	Norway	Portugal	Spain	Sweden	Switzerland	UK
(Price of physical capital / Price of labor)^2	0.0313	0.3335 *	0.2004	-0.5256 **	-0.1466	0.3136 ***	0.1500 ***	-0.1198
	(0.6168)	(1.9896)	(0.2031)	(-2.1410)	(-1.6276)	(3.4307)	(3.2498)	(-0.8556)
(Price of borrowed funds / Price of labor)^2	-0.2002 ***	0.1813	0.0050	-0.2948	-0.0685 *	0.0658	-0.0152	0.1243 *
	(-4.6865)	(1.5779)	(0.0059)	(-1.6449)	(-1.8788)	(1.3711)	(-0.7584)	(1.9924)
year^2	0.0222 ***	-0.0092	0.0185	0.0091	-0.0105	0.0060	0.0163 ***	-0.0158
	(2.8393)	(-0.5696)	(0.0992)	(0.3837)	(-0.6578)	(0.7570)	(2.6889)	(-0.7944)
(Loans) × (Investments)	-0.0596 **	-0.0774	-0.2485	-0.0053	0.0067	-0.2819 ***	-0.0881 ***	-0.0408
	(-2.1151)	(-0.8190)	(-0.4076)	(-0.0870)	(0.2069)	(-3.9936)	(-4.0391)	(-1.0359)
(Investments) × (Non-interest revenues)	0.0059	-0.0437	-0.7902	-0.0722	-0.0126	0.3486 ***	0.0085	-0.1897 ***
	(0.2406)	(-0.7945)	(-1.1730)	(-1.0604)	(-0.4751)	(3.5275)	(0.6335)	(-3.1364)
(Loans) × (Non-interest revenues)	0.0857 **	0.0006	0.3457	0.0874	0.0689	-0.2097 ***	-0.0323 *	-0.0465
	(1.9601)	(0.0142)	(0.5096)	(1.5462)	(1.5013)	(-3.9527)	(-1.9096)	(-0.8661)
(Price of physical capital / Price of labor)	0.1022 **	-0.1775	0.2022	0.5262 ***	0.1713 ***	-0.0028	0.0483 **	0.0030
× (Price of borrowed funds / Price of labor)	(2.5596)	(-1.4445)	(0.2206)	(2.8266)	(3.2964)	(-0.0559)	(2.0176)	(0.0470)
(Loans)	-0.1961 ***	-0.0681	-0.0200	-0.0035	-0.1242 **	-0.1637 **	0.0797 **	0.3671 ***
× (Price of physical capital / Price of labor)	(-4.5823)	(-0.6620)	(-0.0258)	(-0.0371)	(-2.4096)	(-2.4959)	(2.1798)	(4.9485)
(Loans)	0.1271 ***	0.0444	-0.1100	0.1681 *	0.0356	0.0892 *	-0.0171	0.0135
× (Price of borrowed funds / Price of labor)	(3.0457)	(0.4303)	(-0.1920)	(1.8385)	(0.9812)	(2.1040)	(-0.6637)	(0.1757)
(Investments)	0.0119	0.2289 **	-0.0195	0.0986	-0.0331	0.0849	-0.0206	-0.1702 **
× (Price of physical capital / Price of labor)	(0.4853)	(2.3015)	(-0.0216)	(1.2003)	(-0.9806)	(0.8934)	(-0.6636)	(-2.5993)
(Investments)	-0.0415 *	-0.1915 **	0.1362	-0.0338	0.0200	-0.0624	-0.0175	-0.0723 **
× (Price of borrowed funds / Price of labor)	(-1.8896)	(-2.6433)	(0.1762)	(-0.3945)	(0.7852)	(-1.3891)	(-0.8094)	(-2.2958)

Note: t-statistics are given in parenthesis and *** denotes statistical significance at the 1%, ** at the 5% and * at the 10 %

Table 2 : Estimation results of stochastic cost frontier (continued)

Variable	Luxembourg	Netherlands	Norway	Portugal	Spain	Sweden	Switzerland	UK
(Non-interest revenues)	-0.0588	0.0015	0.0334	-0.1602 *	0.0641	0.0525	-0.0496 **	-0.0965 **
× (Price of physical capital / Price of labor)	(-0.1314)	(0.0186)	(0.0371)	(-1.7000)	(1.3852)	(0.6793)	(-1.9615)	(-2.1664)
(Non-interest revenues)	-0.0905 ***	0.0049	-0.0129	0.0050	-0.1024 ***	-0.1008 ***	-0.0139	-0.0286
× (Price of borrowed funds / Price of labor)	(-3.9157)	(0.0723)	(-0.0170)	(0.0607)	(-2.8415)	(-3.0769)	(-0.8599)	(-0.5699)
Loans × year	-0.0109	0.0445	0.0975	0.0927 ***	-0.0119	0.1267 ***	0.0320 ***	0.1325 ***
	(-0.9473)	(1.5602)	(0.2551)	(3.9797)	(-0.6443)	(3.3258)	(3.1388)	(3.9236)
Investments × year	-0.0133 *	0.0009	-0.0676	-0.0200	0.0021	-0.0502 **	-0.0135	-0.0189
	(-1.8392)	(0.0327)	(-0.1065)	(-0.9573)	(0.1803)	(-2.2252)	(-1.5497)	(-1.1235)
Non-interest revenues × year	0.0117	-0.0166	-0.0330	-0.0460 **	0.0064	-0.0479 *	-0.0122 *	-0.0705 ***
	(1.2295)	(-1.1495)	(-0.0593)	(-2.1364)	(0.3700)	(-1.9188)	(-1.8175)	(-3.7014)
(Price of physical capital / Price of labor) × year	-0.0150	-0.0367	-0.0967	-0.0355	-0.0442 *	-0.0630 **	-0.0194	-0.2070 ***
	(-1.4566)	(-1.2314)	(-0.1237)	(-0.8770)	(-1.7401)	(-2.3531)	(-1.6249)	(-5.6862)
(Price of borrowed funds / Price of labor) × year	0.0291 ***	-0.0623 **	0.0161	0.1053 ***	0.0212	-0.0157	0.0066	0.0008
	(3.2266)	(-2.4403)	(0.0485)	(2.6722)	(1.3590)	(-1.4670)	(0.8612)	(0.0370)
σ_v^2	0.4818	0.0629 ***	0.0154 ***	0.0939 ***	0.1349 ***	0.0460 ***	0.0956 ***	0.0423 ***
	(1.6240)	(6.8447)	(6.2401)	(7.5446)	(13.4332)	(3.4992)	(39.7395)	(7.8116)
$\sigma_u^2/(\sigma_v^2+\sigma_u^2)$	0.8943 ***	0.0479 ***	0.0001	0.0001	0.0004 ***	0.9376 ***	0.0442 ***	0.2222 ***
	(12.6565)	(3.9795)	(0.0155)	(0.3144)	(3.4634)	(105.8025)	(8.0534)	(6.1034)
μ	0.2723	0.1097 **	0.0021	0.0068	0.0151	0.4156 ***	0.1300 ***	0.1939
	(0.5859)	(2.1667)	(0.0021)	(0.5971)	(1.5807)	(3.1146)	(9.0850)	(1.5184)
η	-0.0690 **	0.2119 ***	-0.1979	0.4628 ***	0.4503 ***	-0.5205 ***	0.2027 ***	0.1481 **
	(-1.9991)	(5.9360)	(-0.1980)	(3.5249)	(12.1697)	(-6.7626)	(14.7631)	(2.2016)

Note: t-statistics are given in parenthesis and *** denotes statistical significance at the 1%, ** at the 5% and * at the 10 %

Table 3. Measures of regularity conditions on the stochastic frontier function

	S_{01}		S_{02}		S_{03}		MC_{01}		MC_{02}		MC_{03}		H_1		H_2		H_3	
country	number	ratio	number	ratio	number	ratio	number	ratio	number	ratio	number	ratio	number	ratio	number	ratio	number	ratio
Austria	60	43.80%	45	32.85%	32	23.36%	3	2.19%	3	2.19%	3	2.19%	22	16.06%	67	48.91%	90	65.69%
Belgium	19	16.10%	21	17.80%	56	47.46%	38	32.20%	47	39.83%	47	39.83%	74	62.71%	109	92.37%	56	47.46%
Denmark	53	15.63%	40	11.80%	26	7.67%	3	0.88%	86	25.37%	86	25.37%	7	2.06%	287	84.66%	204	60.18%
Finland	35	72.92%	21	43.75%	4	8.33%	14	29.17%	13	27.08%	13	27.08%	11	22.92%	42	87.50%	25	52.08%
France	285	31.42%	140	15.44%	123	13.56%	0	0.00%	594	65.49%	594	65.49%	129	14.22%	683	75.30%	620	68.36%
Germany	427	49.59%	314	36.47%	234	27.18%	15	1.74%	140	16.26%	140	16.26%	378	43.90%	635	73.75%	495	57.49%
Greece	47	38.84%	63	52.07%	70	57.85%	41	33.88%	34	28.10%	34	28.10%	113	93.39%	106	87.60%	67	55.37%
Italy	221	28.85%	288	37.60%	587	76.63%	20	2.61%	0	0.00%	0	0.00%	721	94.13%	581	75.85%	483	63.05%
Luxembourg	253	77.13%	197	60.06%	105	32.01%	39	11.89%	137	41.77%	137	41.77%	44	13.41%	268	81.71%	159	48.48%
Netherlands	83	88.30%	79	84.04%	44	46.81%	13	13.83%	43	45.74%	43	45.74%	67	71.28%	34	36.17%	48	51.06%
Norway	67	85.90%	68	87.18%	25	32.05%	5	6.41%	46	58.97%	46	58.97%	25	32.05%	58	74.36%	46	58.97%
Portugal	15	11.19%	17	12.69%	41	30.60%	5	3.73%	21	15.67%	21	15.67%	12	8.96%	119	88.81%	71	52.99%
Spain	56	15.51%	20	5.54%	40	11.08%	6	1.66%	26	7.20%	26	7.20%	11	3.05%	183	50.69%	211	58.45%
Sweden	18	31.58%	10	17.54%	8	14.04%	9	15.79%	34	59.65%	34	59.65%	21	36.84%	41	71.93%	32	56.14%
Switzerland	314	58.15%	259	47.96%	37	6.85%	13	2.41%	222	41.11%	222	41.11%	31	5.74%	476	88.15%	358	66.30%
UK	57	64.77%	53	60.23%	30	34.09%	29	32.95%	46	52.27%	46	52.27%	53	60.23%	62	70.45%	49	55.68%
TOTAL	2010	40.39%	1635	32.85%	1462	29.38%	253	5.08%	1492	29.98%	1492	29.98%	1719	34.54%	3751	75.37%	3014	60.56%

Note: It reports numbers of inappropriate samples by country.

stochastic cost function for European banks at the same time.[5] Table 4 reports the parameter estimates obtained by the translog stochastic frontier cost function, meta-frontier linear programming and quadratic programming. Standard errors of the estimators for the two meta-frontier estimators are obtained by bootstrapping methods. Treating the sample as the population, we randomly draw 1000 new datasets of the same size as sample with replacement. For each generated dataset, the new meta-frontier parameters are estimated by linear and quadratic programming. Therefore, there are 1000 suites of parameter estimates. The estimated standard errors of the meta-frontier parameters are calculated as the standard deviations of these 1000 sets of new parameters estimates. It is interesting to note that the LP estimators do not significantly deviate from the QP estimators. However, there are substantial differences between the meta-frontier coefficients and the corresponding coefficients of the translog stochastic frontier. For the moment let us just confine our attention to LP estimators.

It may be worth pointing out, in passing, that the data would be improved on the economic regularity conditions in the meta-frontier. In contrast to Table 3, Table 5 shows that the percentages of the observations inconsistent with the regularity conditions decrease substantially.

[5] The translog stochastic frontier cost function for European is obtained by using the data of all banks under consideration.

Table 4: Maximum-likelihood estimates of the translog stochastic frontier for the selected European countries, along with the parameter estimates of the meta-frontier cost function.

Variable	SFA	Meta(LP)	Meta(QP)
Constant	4.1930 (0.1763)	-0.8465 (0.1180)	1.1093 (0.1122)
Loans	-0.1422 (0.0451)	0.6059 (0.0234)	0.2639 (0.0244)
Investments	0.0728 (0.0334)	0.4320 (0.0149)	0.2519 (0.0173)
Non-interest revenues	0.2636 (0.0279)	-0.0444 (0.0190)	0.1998 (0.0259)
Price of physical capital / Price of labor	0.5556 (0.0540)	-0.1000 (0.0331)	0.4331 (0.0324)
Price of borrowed funds / Price of labor	0.2505 (0.0412)	0.6259 (0.0211)	0.3299 (0.0225)
year	-0.0962 (0.0168)	0.1291 (0.0141)	0.0591 (0.0105)
$(\text{Loans})^2$	0.0605 (0.0084)	-0.0216 (0.0036)	0.0231 (0.0041)
$(\text{Investments})^2$	0.0247 (0.0057)	-0.0226 (0.0024)	0.0211 (0.0022)
$(\text{Non-interest revenues})^2$	0.0451 (0.0014)	-0.0086 (0.0024)	0.0165 (0.0025)
$(\text{Price of physical capital / Price of labor})^2$	0.0242 (0.0133)	-0.4412 (0.0086)	-0.3695 (0.0080)
$(\text{Price of borrowed funds / Price of labor})^2$	0.0148 (0.0081)	-0.0023 (0.0022)	0.0064 (0.0028)
year^2	0.0173 (0.0019)	-0.0050 (0.0012)	-0.0105 (0.0011)
(Loans) × (Investments)	-0.0206 (0.0053)	-0.0349 (0.0018)	-0.0395 (0.0028)
(Investments) × (Non-interest revenues)	0.0096 (0.0034)	0.0328 (0.0022)	0.0081 (0.0025)
(Loans) × (Non-interest revenues)	0.0131 (0.0036)	0.0438 (0.0021)	0.0268 (0.0030)
(Price of physical capital / Price of labor) × (Price of borrowed funds / Price of labor)	0.0489 (0.0083)	0.1465 (0.0035)	0.1140 (0.0032)
(Loans) × (Price of physical capital / Price of labor)	0.0259 (0.0085)	0.1419 (0.0042)	0.0638 (0.0036)
(Loans) × (Price of borrowed funds / Price of labor)	-0.0259 (0.0062)	-0.0553 (0.0025)	-0.0244 (0.0024)
(Investments) × (Price of physical capital / Price of labor)	0.0160 (0.0065)	0.0963 (0.0040)	0.0994 (0.0034)
(Investments) × (Price of borrowed funds / Price of labor)	-0.0209 (0.0049)	-0.0601 (0.0019)	-0.0518 (0.0020)
(Non-interest revenues) ×(Price of physical capital / Price of labor)	-0.0507 (0.0048)	-0.1781 (0.0018)	-0.1425 (0.0017)
(Non-interest revenues) × (Price of borrowed funds / Price of labor)	0.0110 (0.0042)	0.0612 (0.0025)	0.0470 (0.0022)
(Loans) × year	-0.0016 (0.0025)	0.0243 (0.0018)	0.0288 (0.0014)
(Investments) × year	0.0036 (0.0021)	0.0097 (0.0014)	0.0145 (0.0012)
(Non-interest revenues) ×year	-0.0022 (0.0017)	-0.0194 (0.0015)	-0.0252 (0.0010)
(Price of physical capital / Price of labor) × year	-0.0254 (0.0029)	-0.0409 (0.0026)	-0.0593 (0.0025)
(Price of borrowed funds / Price of labor) × year	0.0043 (0.0023)	-0.0148 (0.0019)	-0.0027 (0.0015)

Table 5. Measures of regularity conditions on the meta-frontier function

	S_{01}		S_{02}		S_{03}		MC_{01}		MC_{02}		MC_{03}		H_1		H_2		H_3	
country	number	ratio	number	ratio	number	ratio	number	ratio	number	ratio	number	ratio	number	ratio	number	ratio	number	ratio
Austria	63	45.99%	41	29.93%	22	16.06%	0	0.00%	23	16.79%	23	16.79%	22	16.06%	84	61.31%	91	66.42%
Belgium	33	27.97%	19	16.10%	5	4.24%	0	0.00%	30	25.42%	30	25.42%	5	4.24%	32	27.12%	69	58.47%
Denmark	212	62.54%	141	41.59%	49	14.45%	1	0.29%	61	17.99%	61	17.99%	44	12.98%	251	74.04%	228	67.26%
Finland	37	77.08%	20	41.67%	11	22.92%	0	0.00%	31	64.58%	31	64.58%	11	22.92%	39	81.25%	32	66.67%
France	571	62.95%	342	37.71%	73	8.05%	4	0.44%	360	39.69%	360	39.69%	68	7.50%	579	63.84%	578	63.73%
Germany	501	58.19%	248	28.80%	51	5.92%	4	0.46%	301	34.96%	301	34.96%	51	5.92%	524	60.86%	562	65.27%
Greece	50	41.32%	21	17.36%	15	12.40%	0	0.00%	5	4.13%	5	4.13%	15	12.40%	61	50.41%	78	64.46%
Italy	352	45.95%	200	26.11%	133	17.36%	1	0.13%	108	14.10%	108	14.10%	131	17.10%	469	61.23%	490	63.97%
Luxembourg	21	6.40%	89	27.13%	4	1.22%	0	0.00%	1	0.30%	1	0.30%	4	1.22%	33	10.06%	108	32.93%
Netherlands	64	68.09%	32	34.04%	6	6.38%	5	5.32%	38	40.43%	38	40.43%	6	6.38%	51	54.26%	56	59.57%
Norway	7	8.97%	3	3.85%	0	0.00%	0	0.00%	2	2.56%	2	2.56%	0	0.00%	11	14.10%	28	35.90%
Portugal	14	10.45%	16	11.94%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	24	17.91%	94	70.15%
Spain	106	29.36%	68	18.84%	41	11.36%	0	0.00%	29	8.03%	29	8.03%	41	11.36%	177	49.03%	215	59.56%
Sweden	39	68.42%	29	50.88%	16	28.07%	0	0.00%	35	61.40%	35	61.40%	15	26.32%	38	66.67%	42	73.68%
Switzerland	293	54.26%	160	29.63%	62	11.48%	1	0.19%	124	22.96%	124	22.96%	62	11.48%	312	57.78%	360	66.67%
UK	10	11.36%	18	20.45%	3	3.41%	0	0.00%	5	5.68%	5	5.68%	2	2.27%	15	17.05%	31	35.23%
TOTAL	2373	47.68%	1447	29.07%	491	9.87%	16	0.32%	1153	23.17%	1153	23.17%	477	9.58%	2700	54.25%	3062	61.52%

Note: It reports numbers of inappropriate samples by country.

5.2 Cost Efficiency and Technology Gap Ratio

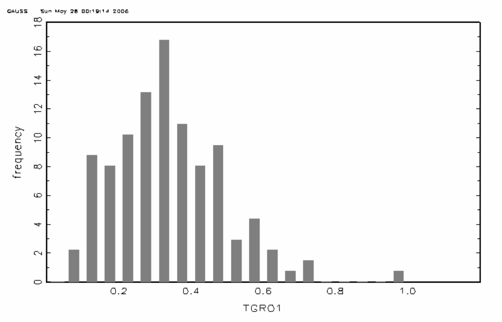
In this section we shift our attention to the estimates of the cost efficiency and the technology gap, calculated by applying the LP estimated parameters. Measures of the TGR, along with the relative cost efficiency (CE) and the meta-frontier frontier (CE*), are reported on Table 6. In terms of CE, the mean values range from 0.47 for Finland to 0.99 for Norway, estimated from equation (7). These results imply that, on average, the potential cost saving for Finland banks is about 53% of their actual costs, which may be attributed to the managerial inefficiency. In contrast, banks in Norway, on average, almost lie on their cost frontier. Overall, for the whole European Banking industry, the mean value of the CE is about 0.71. This is consistent with the results which are found by Altunbas et al. (2001) and Vennet (2002). However, the mean values of CE* vary from 0.06 for UK to 0.36 for Germany. It is obvious that there are quite a few of banks operating far beyond the meta cost frontier. It deserves to take a closer look at some important features of the technology gap. The mean values of the TGR range from 0.1 for UK to 0.55 for Finland. This indicates that the overall level of production technology adopted by the UK banks tends to be the lowest among the sample countries, while the Finnish banks appear to employ superior production process. It is interesting to note that most of the sample countries' cost frontiers, except for Denmark, Norway, Portugal, Sweden and UK, are tangent to the meta cost frontier, as they all have the estimated values of TGR equaling unity.

The frequency distributions for the technology gap ratios could give us more insights into the technology difference among European countries. Figure 2 tells us that there is a good deal of variability in the technology gap ratios for banks in all countries. We find that in many countries banks adopt the inferior technology, since the frequency distributions for the technology gap ratios are skew to the right. Banks in Germany own the highest mean cost efficiencies relative to the meta-frontier. In contrast, banks in Norway have the highest cost efficiencies (CE) relative to their stochastic frontier, while its average TGR estimate is low, which in turn results in low CE* measure.

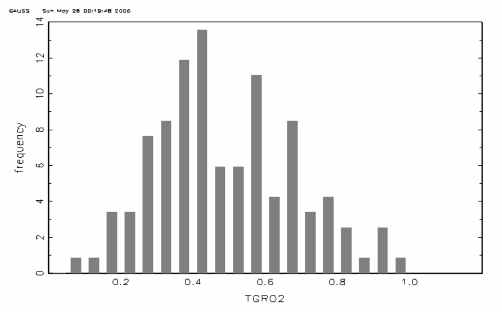
Table 6. Summary Statistics for TGRs and the cost efficiency measures for the sample countries

Country/Statistic	Mean	Minimum	Maximum	St. Dev.	Country/Statistic	Mean	Minimum	Maximum	St. Dev.
Austria					*Luxembourg*				
CE	0.7637	0.5514	0.9580	0.0811	CE	0.6188	0.1965	0.9468	0.2052
TGR	0.3568	0.0516	1.0000	0.1653	TGR	0.2221	0.0044	1.0000	0.1843
CE*	0.2715	0.0388	0.8247	0.1288	CE*	0.1336	0.0035	0.7638	0.1143
Belgium					*Netherlands*				
CE	0.6585	0.4663	0.9518	0.1209	CE	0.6749	0.2397	0.9447	0.1775
TGR	0.4700	0.0251	1.0000	0.2212	TGR	0.3676	0.0003	1.0000	0.2363
CE*	0.3129	0.0143	0.7348	0.1686	CE*	0.2393	0.0002	0.8720	0.1768
Denmark					*Norway*				
CE	0.6302	0.3321	0.9800	0.1391	CE	0.9989	0.9979	0.9996	0.0005
TGR	0.4804	0.0108	0.9695	0.1920	TGR	0.2709	0.1096	0.8955	0.1443
CE*	0.2926	0.0062	0.7201	0.1138	CE*	0.2706	0.1095	0.8942	0.1441
Finland					*Portugal*				
CE	0.4731	0.0677	0.9048	0.2525	CE	0.9073	0.5174	0.9944	0.0975
TGR	0.5475	0.0941	1.0000	0.2668	TGR	0.3096	0.0800	0.8314	0.1349
CE*	0.2235	0.0327	0.5939	0.1215	CE*	0.2825	0.0795	0.8262	0.1336
France					*Spain*				
CE	0.7452	0.1850	0.9857	0.1727	CE	0.8545	0.2048	0.9922	0.1424
TGR	0.4038	0.0005	1.0000	0.1415	TGR	0.3248	0.0277	1.0000	0.1184
CE*	0.3048	0.0003	0.9164	0.1371	CE*	0.2829	0.0266	0.9316	0.1214
Germany					*Sweden*				
CE	0.8086	0.1118	0.9913	0.1421	CE	0.8653	0.5120	0.9960	0.1338
TGR	0.4290	0.0066	1.0000	0.1570	TGR	0.3955	0.0403	0.9855	0.2688
CE*	0.3551	0.0061	0.8203	0.1602	CE*	0.3159	0.0397	0.8004	0.1848
Greece					*Switzerland*				
CE	0.6227	0.3805	0.9071	0.1268	CE	0.6967	0.2590	0.9757	0.1583
TGR	0.4532	0.0791	1.0000	0.1805	TGR	0.4767	0.0129	1.0000	0.1403
CE*	0.2854	0.0575	0.7311	0.1440	CE*	0.3355	0.0091	0.7716	0.1292
Italy					*UK*				
CE	0.5598	0.1437	0.9668	0.1783	CE	0.6943	0.2768	0.9238	0.1333
TGR	0.5234	0.0096	1.0000	0.1603	TGR	0.0963	0.0032	0.2130	0.0589
CE*	0.2868	0.0089	0.7582	0.1150	CE*	0.0665	0.0025	0.1632	0.0432
Total									
CE	0.7145	0.0677	0.9996	0.1906					
TGR	0.4140	0.0003	1.0000	0.1851					
CE*	0.2919	0.0002	0.9316	0.1473					

Note: The linear programming parameter estimates are used in this table.



Austria



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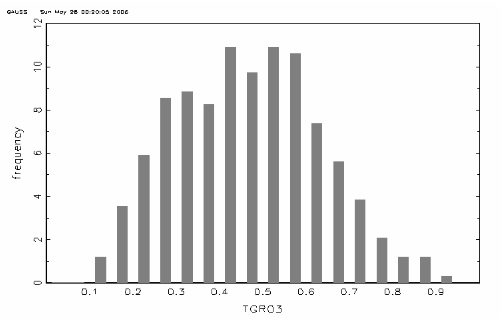

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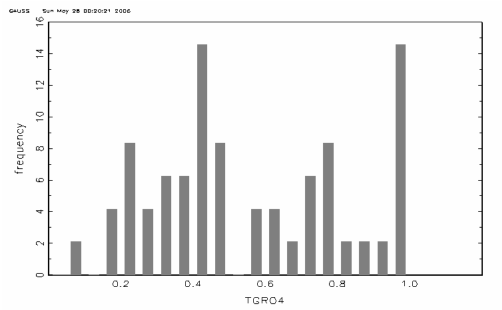

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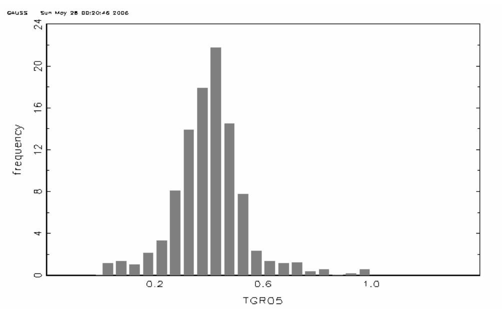

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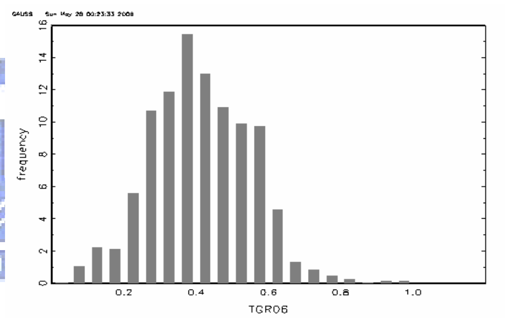

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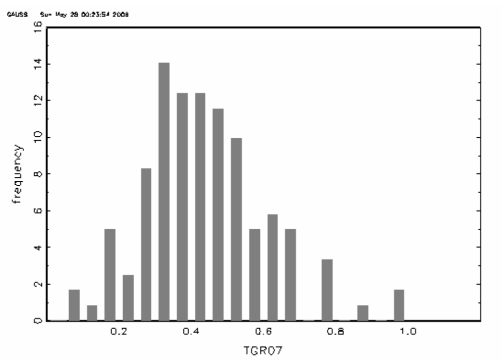
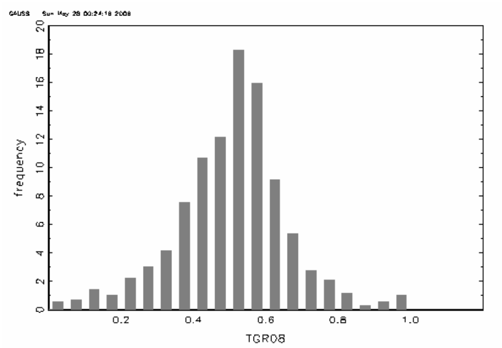
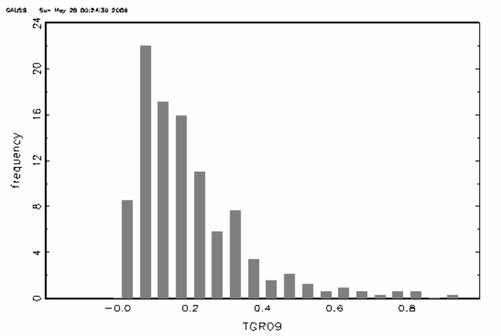


Greece

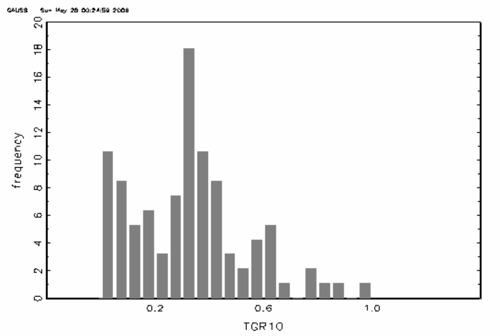


Italy

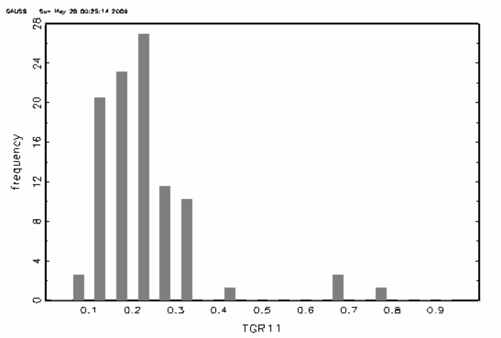
Figure 2. Frequency distributions of TGRs in different countries (continued).



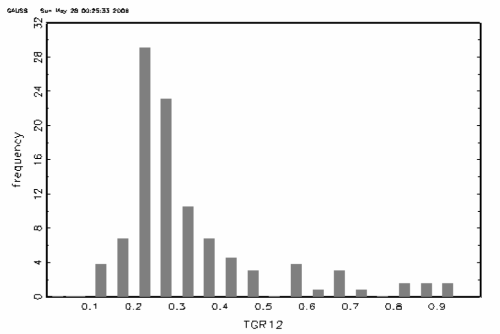
Luxembourg



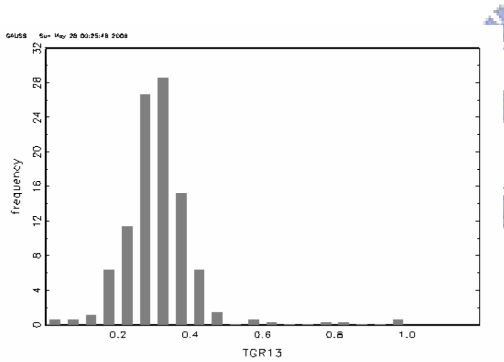
Netherlands



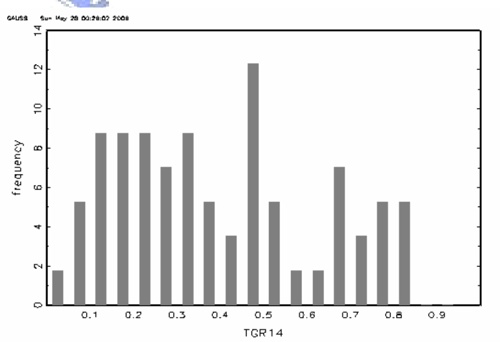
Norway



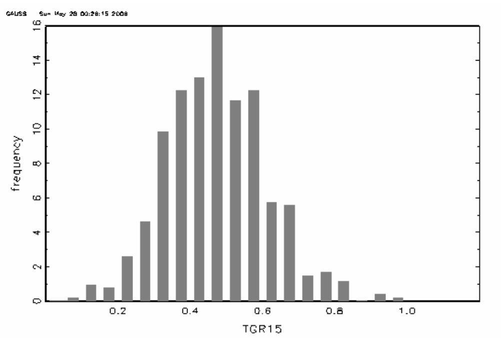
Portugal



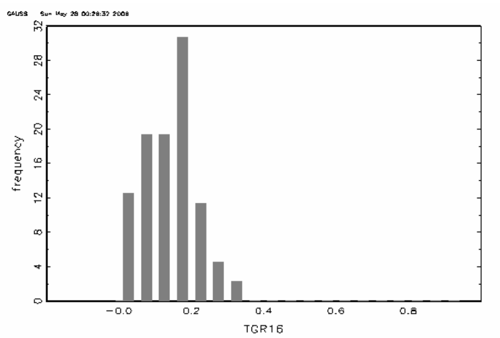
Spain



Sweden



Switzerland



UK

Figure 2. Frequency distributions of TGRs in different countries (continued).

One may ask whether the relative cost efficiency scores are correlated with the technology gap ratios. This information provides a potential link between technology advancement and production efficiency levels. Figure 3 indicates that the two measures are negatively associated with each other in a medium degree, with Luxembourg and UK exhibiting larger variability. This indicates that in a country which faces swift technical innovations (higher TGR) over time, banks may adopt such innovations in a tardy manner. This type of rigidity hinders banks from optimally selecting input levels, due possibly to the existence of quasi-fixed inputs, because they are incapable of adjusting instantly.

Having access to a panel of data incorporating both cross-sectional and time series properties, we are able to analyze the relative cost efficiency and the technology gap ratio over time. The relative cost efficiency scores and the technology gap ratios are averaged across time, respectively. These figures help us understand the evolution of the measures for the sample banks over time. Figure 4 shows that both CE and TGR gradually grow with time, but the mean values of the TGR slightly decrease after 2001.

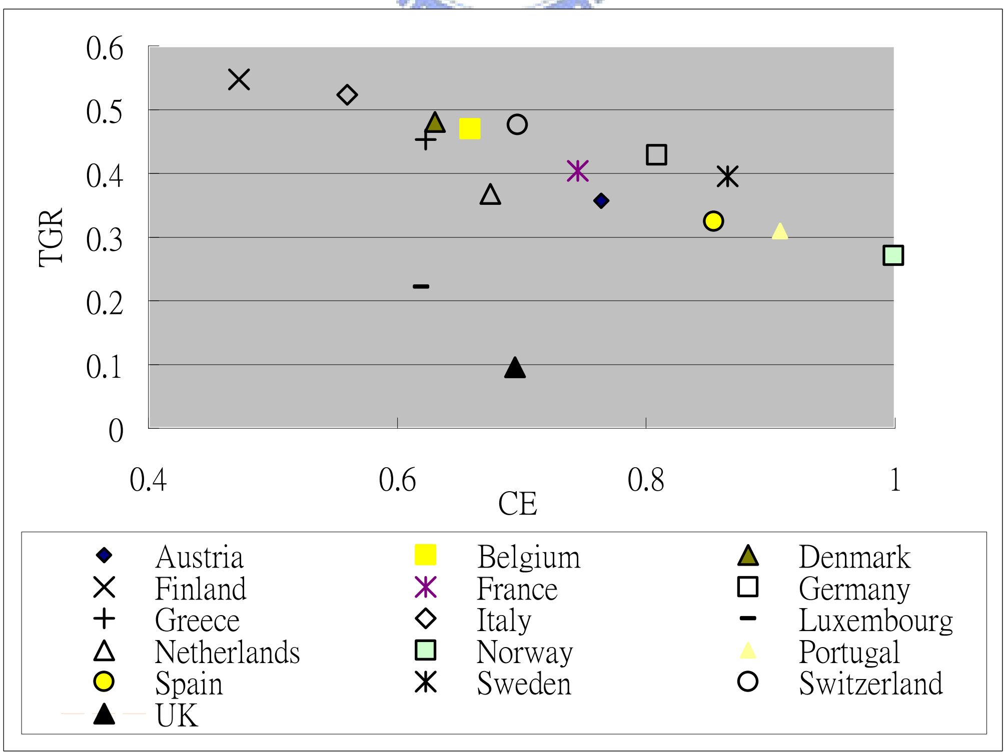


Figure 3. Relationship between CE and TGR

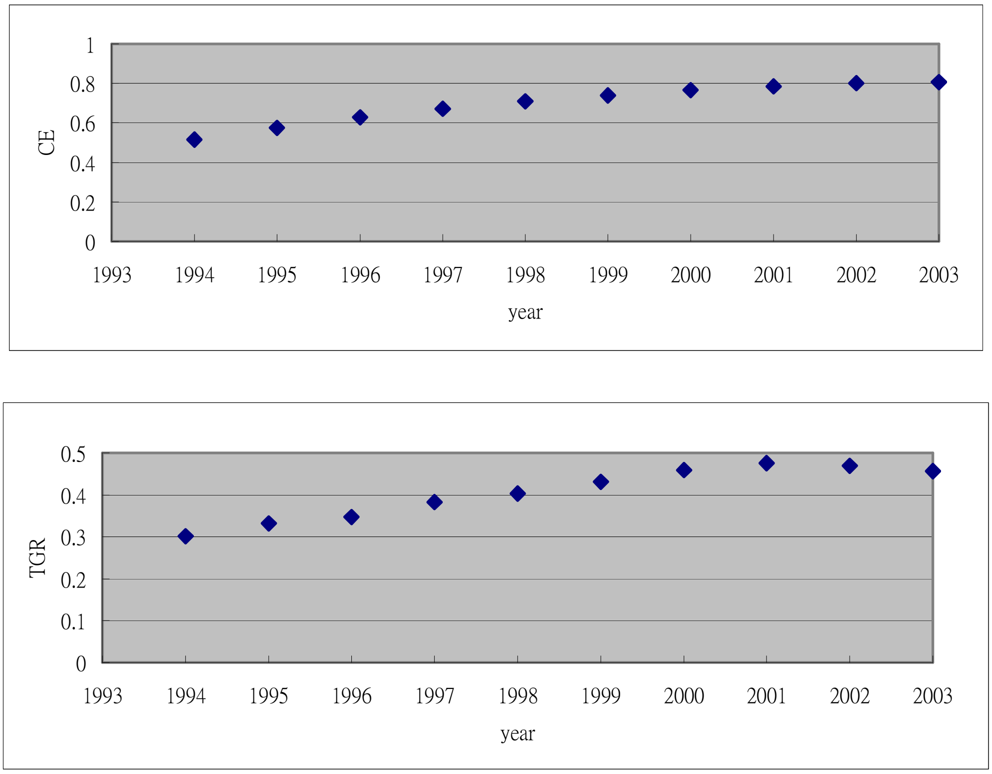


Figure 4. Mean values of CE and TGR over time.

5.3 Scale and Scope Economies

According to equations (10) and (11), the economies of scale and scope measures for banks are calculated using their corresponding stochastic frontier parameters and the estimated meta-frontier parameters separately. The mean values of the scale and scope economies are reported in Table 7. Our results show that the stochastic frontier estimates are insignificantly different from the meta-frontier estimates in evaluating economies of scale, while the reverse is true in the evaluation of economies of scope. It is seen that estimates of the economies of scope computed by applying the parameter estimates of SFA vary substantially. In contrast, the same scope economies estimates from the meta-frontier cost function are relatively stable. Lau and Yotopoulos (1989) gave some explanations for this dissimilarity. The meta-frontier approach pools data from different countries to estimate a common production function, thus increasing the range of variation of the independent variables and the number of observations. As a result, more precise and reliable parameter estimates may result. Broadly speaking, the European banking industry as a whole exhibits both scale and scope economies. We are led to conclude that it is advantageous for banks to enlarge their production scale and to diversify their financial products.

Table 7. Estimated economies of scale and scope by SFA and the meta-frontier cost function

	Scale economic		Scope economics	
country	SFA	Meta	SFA	Meta
Austria	0.957721	0.557122	-0.81827	-0.60387
Belgium	0.332715	0.534222	0.138739	-0.79004
Denmark	0.339556	0.505596	54.96917	-0.40001
Finland	0.494305	0.345492	2.29E+08	-0.57397
France	0.377457	0.477611	-0.14551	11.80085
Germany	0.70236	0.500859	648627.9	0.158351
Greece	0.547029	0.63826	-0.55872	-0.55672
Italy	0.394353	0.57565	557.7577	0.278707
Luxembourg	0.3043	1.041681	7.212447	-0.50003
Netherlands	0.301914	0.483457	10.8347	52.32479
Norway	0.67542	0.878654	1.43E+10	-0.58817
Portugal	0.898057	0.863431	-0.75354	-0.76151
Spain	0.451054	0.65595	-0.69082	-0.80118
Sweden	0.48533	0.247593	332546.8	-0.69661
Switzerland	0.589221	0.519883	8.322246	-0.55632
UK	0.136416	0.896425	1685.322	-0.56317
mean	0.49157	0.581041	2.27E+08	2.928355

6. Conclusion

This thesis investigates the cost efficiencies of the commercial banks across 16 European countries for the years 1994-2003. In the conventional studies, the cost efficiency of a bank employing one type of technology is unable to be directly comparable with other banks employing different types of technology. The adoption of the meta-frontier function provides a possible solution to this problem.

The model, proposed by Battese et al. (2004), assumes that there is only one data-generation process for the banks operating under a given technology for each country.

We first introduce the stochastic cost frontier model to the banking industry for each country. Next, the meta-frontier cost function is defined as a deterministic parametric function such that its parameter values must be less than or equal to the deterministic components of the stochastic cost frontier of the different countries involved. It is interesting to note that the methodology proposed allows for analyzing the TGR among countries by using a decomposition technique. The TGR mainly evaluates the degree of technology gap for the country whose currently available technology adopted by its banks lags behind the technology available for all countries. Then, we measure the TGR of the banks by using the ratio of the potential cost that is defined by the meta-frontier function to the cost for the frontier function for their country given the observed outputs and input prices.

According to the empirical results, we note that all European countries' banks are exploiting different types of technology. This means that a meta-frontier model may be an appropriate choice for this kind of the cross country study. Broadly speaking, there is substantial variability in the technology gap ratios for banks in all European countries. Many banks are found to adopt the inferior technology in some countries. As the European financial markets become more competitive and highly integrated, it is obvious to see that each country's banking competitive viability will be greatly determined by its improvability on technology.

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