EUROPEAN CENTRAL BANK

WORKING PAPER SERIES

NO 701 / DECEMBER 2006

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IS THERE A SINGLE FRONTIER IN A SINGLE EUROPEAN BANKING MARKET?

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In 2006 all ECB publications feature a motif taken from the €5 banknote.

1 We thank Rob Alessi, George Battese, Jacob Bikker, Chris O'Donnell, William Greene, Michael Koetter, Clemens Kool, D.S. Prasado Rao and two anonymous referees for their helpful comments. This paper is based on an older study that was published in the working paper series of De Nederlandsche Bank under the title "Comparing Efficiency in European Banking: a Meta Frontier Approach". The paper has benefited from presentations at the Hellenic Workshop on Efficiency and Productivity Measurement (2002), De Nederlandsche Bank (2003), German Bundesbank (2004), Utrecht School of Economics (2004) and Norges Bank (2006). The authors are also grateful to Barbara Huettmann and Danny van den Kommer for providing most efficient research assistance. This paper originates from a visiting scholarship of Heiko Schmiedel at De Nederlandsche Bank. He would like to thank De Nederlandsche Bank for its hospitality and generous support. The views expressed are those of the authors and do not necessarily reflect the views of the European Central Bank and De Nederlandsche Bank. The usual disclaimers apply.

2 Corresponding author: Utrecht School of Economics, Utrecht University, Vredenburg 138, 3511 BG, Utrecht, The Netherlands; e-mail: j.bos@econ.uu.nl

3 European Central Bank, Kaiserstrasse 29, 60311 Frankfurt am Main, Germany; e-mail: heiko.schmiedel@ecb.int

Address
Kaiserstrasse 29
60311 Frankfurt am Main, Germany

Postal address
Postfach 16 03 19
60066 Frankfurt am Main, Germany

Telephone
+49 69 1344 0

Internet
http://www.ecb.int

Fax
+49 69 1344 6000

Telex
411 144 ecb d

ISSN 1561-0810 (print)
ISSN 1725-2806 (online)

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Abstract

This paper attempts to estimate comparable efficiency scores for European banks operating in the Single Market in the EU. Using a data set of more than 5000 large commercial banks from all major European banking markets over the period 1993-2004, the application of meta-frontiers enables us to assess the existence of a single and integrated European banking market. We find evidence in favor of a single European banking market characterized by cost and profit meta-frontiers. However, compared to the meta-frontier estimations, pooled frontier estimations tend to underestimate efficiency levels and correlate poorly with country-specific frontier efficiency ranks.

Key words: X-efficiency, stochastic frontiers, banking, meta-frontiers, technology gap ratios
JEL classification: G21, L11, L22, L23

Non-technical summary

The past decades have witnessed a string of regulatory changes, mergers and technological advances that together have re-shaped Europe's banking markets. As a result, today's European banking markets differ substantially from the past. All conditions had been set for the effective creation, existence and benefits of a single European banking market fostering cross-border competition and increase financial integration. But looking back, Berger et al. (2002) observe that despite the enormous potential, the immediate effect of all initiatives has been limited to an increase in the consolidation of banks and banking markets at the local level. For this reason, it is of topmost interest for policy makers, regulatory and monetary authorities, as well as expert practitioners and researchers, to know more about the true underlying differences or similarities of bank performance and efficiency among European countries in order to better adjust to the new environment, to undertake strategic decisions, to benchmark banking institutions performance, and to prepare for increasing competition in domestic as well as cross-border markets.

Most previous work in this field estimates the efficiency of banks either in their purely separate national context or benchmarks banks in different countries by assuming that they access to the same conditions and technology. However, since efficiency measurement is a relative concept these approaches do not settle the issue of efficiency differences among banks across countries.

Taken together, this raises the question how comparable Europe's major banking markets are. This paper takes a systematic attempt to provide 'truly' comparable efficiency scores for the European banking industry. It applies a new method for comparing European bank efficiency, while taking into account the fact that banks in different countries may not operate under the same circumstances due to differences in technology, competition, supervision, etc.

First, the paper evaluates the efficiency levels of the banking industry by estimating banks' country-specific and pooled cost and profit functions. Second, we identify and estimate a so-called "meta-frontier". This meta-frontier is viewed as an "envelope" cost and profit function that encompasses groups of banks that operate under different circumstances. In contrast to standard estimation models, it allows for a fair comparison of bank efficiency scores across different countries.

Overall, the empirical results suggest that average cost and profit efficiency varies considerably across Europe. Our "meta-model" provides bank efficiency scores that are close to the efficiency levels from country-specific estimations. As technology differences seem to converge across Europe, we find evidence in favor of a single, integrated European banking market characterized by a single set of rules, equal access and equal treatment.

Whether individual banks can benefit from the current situation remains to be seen. Based on our results, banks that are very efficient in their home country may find it hard being equally successful abroad. Seen in this light, our analysis may help to explain the limited number of cross-border mergers that have taken place in the European banking market since the inception of the single banking market. Our profit model results may imply that local competition is an important determinant of bank efficiency.

1 Introduction

The past decades have witnessed a string of regulatory changes, mergers and technological advances that together have re-shaped Europe's banking markets. In the European Union, the First Banking Coordination Directive (1977), the EU White Paper (1985) and the Second Banking Coordination Directive (1988) finally led to the establishment of the Single Market for Financial Services on January 1, 1993.

As a result, in the remainder of the 1990s, we observe European banking markets that are radically different from what was common in the past. Equally important, however, compared to each other these banking markets were *in principle* and *de jure* perceived as being more homogenous than ever. All conditions had been set for the effective creation, existence and benefits of a single European banking market. But looking back, Berger et al. (2002) observe that despite the enormous potential, the immediate effect of all the above-described initiatives has been limited to an increase in the consolidation of banks and banking markets at the local level. For example, the number of cross-border mergers has been very limited.

Taken together, this raises the question how comparable Europe's major banking markets are. In this paper, we attempt to answer this question by analyzing whether commercial banks in 15 European countries share a common benchmark, that is a common cost or profit frontier for the period 1993-2004. As stated by Molyneux et al. (1997), efficiency is one of the crucial "elements that impact on the effects of the single financial market place" (p. 9). In focusing on X-inefficiency, we redress an imbalance in the established efficiency literature. This imbalance is caused by the fact that prior studies compare X-inefficiencies assuming that banks operate under a single frontier technology. However, many researchers note that the assumption of a single frontier is an unsettled issue in the efficiency literature (cf. Dietsch and Lozano-Vivas, 2000; Chaffai et al., 2001; Lozano-Vivas et al., 2001; Bikker, 2002). In this paper, we estimate comparable efficiency scores for banks in different countries, possibly operating with different technologies and hence under different frontiers.[2] To this purpose, we use a meta-frontier model that allows us to calculate efficiency scores and technology gaps for European banks. This way, we can compare efficiency scores across countries with different frontiers and measure the degree of homogeneity of Europe's largest banking markets by assessing their distance to a European meta-frontier.

[2] As we explain in more detail in our methodology section, we allow transformation functions to differ across countries.

In the next section, we present a brief review of existing literature that compares efficiency across European banks. Then, in our methodology section we introduce a standard stochastic frontier profit and cost model, respectively. We subsequently derive a meta-frontier for each of these models. Next, we describe our data and introduce the variables we use for our analysis. What follows is a description of our empirical results. We start by describing technology gaps between country-specific frontiers and our meta-frontiers. Then, we study the (rank) stability of efficiency scores. Finally, we review trends in technology gaps and efficiency. In the final section, we conclude and draw a preliminary research agenda.

2 Literature

To our knowledge, no other paper exists that applies stochastic meta-frontiers to banking. In this section, we therefore present a brief, non-exhaustive overview of some of the work that has been done on comparing the X-efficiency of banks.

The bank efficiency literature has a long tradition and cumulated to a substantial number of studies with different methodologies, scope, and results, e.g. Berger and Humphrey (1997) and Berger et al. (1999). For the U.S., Berger and Humphrey (1991) and Berger and Mester (1997) established the consensus that banks could improve their cost and profit efficiency more by reducing frontier inefficiencies than by reaching some optimal level of scale and scope economies to minimize average costs and to maximize profits. A number of other studies has emphasized conceptual issues (Lovell, 1993) or introduced risk variables, e.g. Berg et al. (1992), McAllister and McManus (1993), Mester (1996), Berger and DeYoung (1997). These studies have in common that they focus on a single country (mainly the U.S.). Other studies in this category established that foreign-owned banks are relatively less efficient as domestic-owned owned banks (cf. Hasan and Hunter, 1996; Mahajan et al., 1996; DeYoung and Nolle, 1996; Chang et al., 1998; Peek et al., 1999).

The number of cross-country comparative studies is still limited.[3] Most of the cross-country frontier studies focus on the European market. The efficiency results for European banks differ between studies depending on the estimation technique, sample size, input and output specifications, and period. Despite their differences, some tentative results are noteworthy. Roughly in line with the experiences in the U.S., most studies suggest that average cost efficiency for European banking industries ranges from 70 percent to 80 percent while profit efficiency levels are found to be lower, at around 50 – 60 percent. Pastor et al. (1997) conclude that the banking industry in France, Spain, and Belgium

[3] Exceptions include Berg et al. (1993), Fecher and Pestieau (1993), Vander Vennet (1994), Bergendahl (1995), Berg et al. (1995), Allen and Rai (1996), Ruthenberg and Elias (1996), Pastor et al. (1997), and Vander Vennet (1999).

is more efficient compared with the banking experiences from Germany, U.K., and Austria.

Sheldon (1999) uses unconsolidated data for 1,783 commercial and savings banks in the EU, Norway, and Switzerland for the period 1993-1997. He uses Data Envelopment Analysis (DEA) to examine cost and profit efficiency and finds that large banks, specialized banks, and retail banks are more cost and profit efficient than small banks, diversified banks, and wholesale banks, respectively. Average frontier efficiency is fairly low, at about 45 percent for costs and 65 percent for profit. Banks in Denmark, France, Luxembourg, and Sweden have the highest average efficiency, and banks in Greece, Italy, Portugal, Spain, and U.K. have the lowest average efficiency.

Altunbas, Evans and Molyneux (2001) ask a similar question and focus on the German banking market, for the period 1989-1996. [4] They distinguish between private commercial banks, public savings banks and mutual cooperative banks. Their main finding is that private commercial banks are relatively cost and profit inefficient when compared to the other banks.

Bos et al. (2005) also study the German banking market, and focus on the effects of accounting for heterogeneity on bank efficiency scores. For the period 1993-2003, they find that banks of different sizes, geographic origins, and types (cooperative and savings) have markedly different cost efficiency scores. However, more importantly they find that results vary greatly with the method with which this heterogeneity is controlled for. With this finding, they touch directly upon what we call the benchmarking paradox: we engage in a benchmarking exercise in order to measure performance differences, but in order to do so, we have to assume a common benchmark.

In fact, this paradox is apparent in the cross-border literature, where banks are usually compared to a common efficient frontier, thereby assuming that banks across different countries have access to the same technology. However, when the frontier is applied to each sample country and the performance of each individual banking institutions is compared against the best-practice bank in that country, efficiency results cannot be compared across borders. Recent research initiatives attempt to avoid the bias inherent in cross-border bank efficiency comparisons by incorporating country-specific environmental conditions (cf. Dietsch and Lozano-Vivas, 2000; Chaffai et al., 2001; Lozano-Vivas et al., 2001; Sathye, 2002; Grigorian and Manole, 2002; Lozano-Vivas et al., 2002).

[4] Other recent studies by the same authors have advanced the research on bank efficiency by applying alternative frontier methodologies to estimate scale economies and, X-inefficiencies, and technical change (Molyneux et al. (1997); Altunbas et al. (2001)).

For example, Dietsch and Lozano-Vivas (2000) emphasize that the assumption of a common frontier could yield misleading efficiency results of firms from different countries as such approaches do not control for cross-country differences in regulatory, demographic, and economic conditions that are beyond a firm's control. As a result, the authors find that efficiency scores based on the common frontier model tend to be low (high) for firms that operate under bad (good) home country conditions.

Similarly, Lozano-Vivas et al. (2001) simulate the performance for each of the banking market if average banks decide to operate in any other country. They find that some banks can indeed be expected to perform well if they operate in another country. Finally, Bos and Kolari (2005) compare both large and small independent European and U.S. banks, respectively. They test whether banks from Europe and the U.S. operate under the same profit and cost frontier, and though they find evidence in favor of a single profit frontier they reject a single cost frontier.

These initiatives, as mentioned earlier, do not settle the issue of cross-border efficiency comparisons of banks having access to different types and standards of technologies in different countries. This paper attempts to add to the established literature by estimating 'truly' comparable efficiencies across countries using a meta-frontier model to account for different underlying technologies in the EU banking industry. We next turn to further details of the methodology.

3 Methodology

Efficiency benchmarking models in general, and stochastic frontier models in particular, rely on an often implicit set of assumptions when used to assess and compare firm-specific efficiency. We briefly discuss a number of these assumptions and the implications they have for a stochastic frontier analysis (SFA) of banking markets. First, we often assume that firms included in a sample compete in some way. Of course, this assumption is by no means a necessary condition for estimating a stochastic frontier model for a specific sample. But it becomes important when we wish to assess the ex ante and ex post relevance of the results from the SFA. A classic way to test this assumption would be to look at cross-price elasticity of demand. For banks, this is notoriously difficult. We tend to not know many prices that banks charge: bank-specific interest rates, for example, are almost always proxied for. And we tend to not agree what comprises the prices that banks charge: should we for example include service charges on a loan, or just the interest rate?

A second, related assumption refers to the definition of the market these firms operate on. Are the products offered by the firms in the sample completely homogenous? Or are firms offering close substitutes also included?[5] Thirdly, once there is agreement on the degree of homogeneity of the outputs, we have to agree on the total production set. Depending on the degree of specialization, not all firms in the sample may use the same inputs and outputs. Bearing in mind that most models cannot handle zero inputs or outputs, this generally involves limiting the sample to those firms that make use of the full range of inputs and outputs defined by the production set (Berger et al. 2000).

A fourth and related assumption then concerns the functional form of the production function. Upon applying duality, the same holds for a cost or profit model. Not all firms may use the same production techniques. Depending on the degree of specialization of the firm and the role of its environment, firms may have different transformation function and a larger or smaller opportunity set – even if they have the same production set. Thus, we are faced with the paradoxical situation that in order to benchmark the differences in efficiency of firms in our sample, we have to assume that these firms operate under the same frontier. This observation may seem trivial, but it is far less so when we keep in mind that in most benchmarking exercises we are most interested in those firms that are furthest removed from the frontier. Especially those firms may not be operating under the same frontier, with the same technology. It is this problem that we focus on in this paper.

3.1 A Stochastic Frontier Model

Stochastic frontier models are a particular class of benchmarking models. As with most benchmarking models, SFA yields firm-specific estimates that are comparable. More precisely, it yield firm-specific efficiency estimates drawn from the same distribution, with the same transformation function T and the same pricing opportunity set H.[6] When we do not consider a production model but instead estimate a cost and/or profit model we rely on duality, but implicitly still require that our efficiency estimates result from the same input-demand and output-supply functions.[7]

For a cost model and with $k = 1, ..., K$ banks in $t = 1, ..., T$ periods, we define cost as TC_{kt}, output prices as P_{kt}, and outputs as Y_{kt}. Let W_{kt} be input prices

[5] Think in this respect for example of a cost model where some of the outputs are considered substitutes. If an output is produced by some firms in the sample, and not by others, then no logarithmic model can be estimated for the whole sample (bearing in mind that there is no neutral transformation for this logarithmic model).
[6] Cf. Coelli (chapter 3, 1998).
[7] We refer to Bos (2002) for the precise derivation and assumptions.
[8] We use lower case symbols to denote logarithms. We introduce the profit model via footnotes. For the profit model, profit $= \Pi_{kt}$ is maximized.

and X$_{kt}$ be inputs.[8] Also, we include control variables Z$_{kt}$. The minimization problem then becomes:[9]

$$\underset{P,X}{Min} TC_{kt} = W_{kt}^{'} X_{kt} \quad s.t. \, T(X_{kt}, Y_{kt}, Z_{kt}) = 0 \tag{1}$$

Next, we solve simultaneously for $P_{kt}^{*}(Y_{kt}, W_{kt}, Z_{kt})$ and $X_{k}^{*}(Y_{k}, W_{k}, Z_{k})$ and substitute into equation (1):[10]

$$TC_{kt}^{*} = W_{kt}^{\prime} X_{kt}^{*}(Y_{kt}, W_{kt}, Z_{kt}) = \tilde{TC}_{kt}\,(Y_{kt}, W_{kt}, Z_{kt}). \tag{2}$$

Hence, the optimal, efficient cost level is a function of the number of outputs, input prices, and the control variable Z_{kt}. All inputs are variable inputs, and factor prices W_{kt} are exogenous. We allow for the impact of technological change on efficiency, by including a linear and quadratic trend term as well as trend interaction terms.[11] With a 3-input, 3-output translog specification, the cost frontier model for bank k in period t is then represented in logs as:[12]

$$tc_{kt} = a_0 + \sum_{i=1}^{3} a_i m_{ikt} + \sum_{i=1}^{3} \sum_{j=1}^{3} a_{ij} m_{ikt} m_{jkt} + \frac{1}{2} \sum_{i=1}^{3} a_{ii} m_{ikt}^2 + v_{kt} + u_{kt}, \text{ for } i \neq j \tag{3}$$

where the endogenous variable tc_{kt} is defined as the (log of) total cost of bank k in period t and m consists of outputs y, input prices w, and control variable z (equity). A time trend t captures technological change, and $\varepsilon_{kt} = v_{kt} + u_{kt}$.[13] The random error term ν_{kt} is assumed i.i.d. with $\nu_{kt} \sim N(0, \sigma_{\nu}^2)$ and independent of the explanatory variables (see Aigner and Schmidt, 1977 and Coelli et al.,1998). The efficiency term u_{kt} is i.i.d. with $u_{kt} \sim |N(\mu, \sigma_u^2)|$ and it is independent of ν_{kt}. It is drawn from a non-negative distribution truncated at μ instead of zero. A point estimator of technical efficiency is

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[9] For the profit model, we have $\underset{P,X}{Max} \Pi_{kt} = P_{kt}^{\prime} Y_{kt} - W_{kt}^{\prime} X_{kt} \quad s.t. \, T(X_{kt}, Y_{kt}, Z_{kt}) = 0,\ H(P_{kt}, Y_{kt}, W_{kt}, Z_{kt}) = 0$.

[10] For the profit model, we have: $\Pi_{kt}^{*} = P_{kt}^{*}(Y_{kt}, W_{kt}, Z_{kt})^{\prime} Y_{kt} - W_{kt}^{\prime} X_{kt}^{*}(Y_{kt}, W_{kt}, Z_{kt}) = \tilde{\Pi}_{kt}\,(Y_{kt}, W_{kt}, Z_{kt})$.

[11] Cf. Lang (1996) and Altunbas et al. (1999). For a discussion of the translog specification, cf. Berger and Mester (1997) and Swank (1996).

[12] Cf. Färe and Lovell (1978), Greene (1980), Jondrow et al. (1982), and more recently Battese and Coelli (1988). Duality requires the imposition of symmetry and linear homogeneity in input prices to estimate our cost model (see Beattie and Taylor 1985; and Lang and Welzel 1999). Whether we also should impose this on the profit model is a matter of debate (cf. Kumbhakar and Lovell, 2000), but doing so does not affect our estimates.

[13] We estimate all models using the three-step procedure outlined in Kumbhakar and Lovell (2000), and reparameterize σ_u^2 and σ_ν^2 by taking $\sigma^2 = \sigma_u^2 + \sigma_\nu^2$ and $\lambda = \sigma_u / \sigma_\nu$. We follow Waldman (1982) and check the skew in the residuals of the OLS estimation to ensure that estimating our stochastic frontiers with maximum likelihood estimation is appropriate.

given by $E(u_{kt}|\varepsilon_{kt})$, i.e., the mean of u_{kt} given ε_{kt}. Estimates of bank-specific cost efficiency are obtained by calculating:

$$CE_{kt} = [\exp(-u_{kt})]^{-1}. \quad (4)$$

This measure takes on a value between 0 and 1.[14] Cost efficiency equals one for a fully efficient bank that operates on the efficient stochastic frontier.

3.2 A Meta-Frontier Model

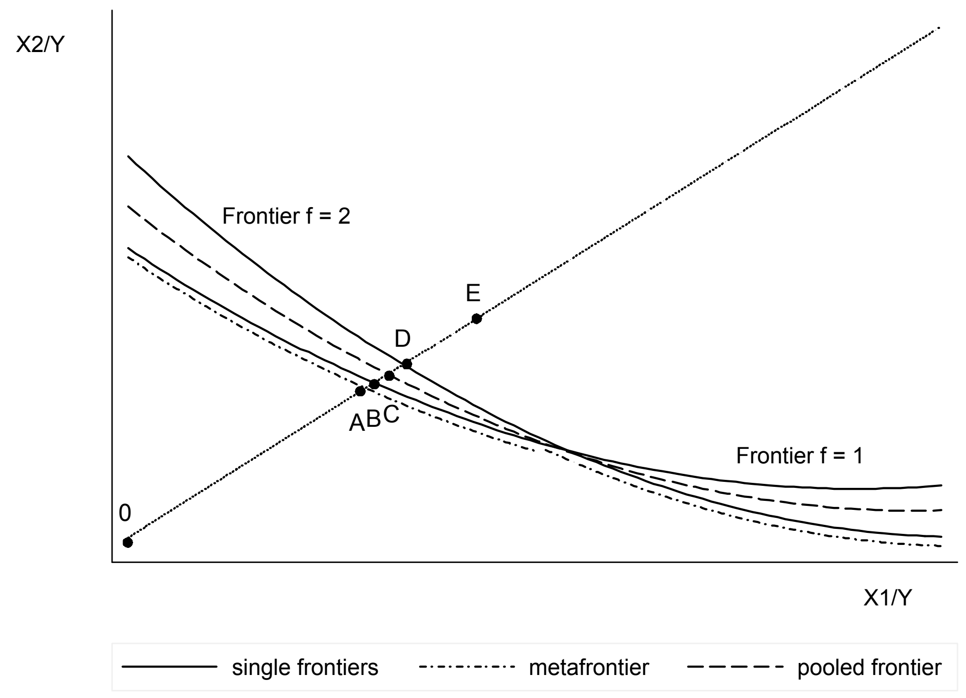
The methodological issues associated with deriving bank and country-specific efficiency measures from single cross-country frontiers are increasingly being discussed in the literature. This is highlighted by the growing number of studies that investigate (unobserved) heterogeneity among banks in stochastic frontier analysis (cf Greene 2005, and Bos et al. 2005). Broadly speaking, the literature discusses two possible effects of this heterogeneity. The first is a parallel shift in the frontiers for different groups of banks (from different regions, size classes, specializations). Typically this is done by changing the specification of the deterministic kernel of the frontier model, for example by including group-specific fixed effects. A second effect discussed in the literature concerns the impact of heterogeneity on the distributions of the random error term and or the inefficiency term. Here, banks are still assumed to operate under a common frontier, but the accuracy with which we estimate this frontier and/or the distibution of efficiency under the frontier differs per group.

Here, we discuss a third, and potentially very important facet of the benchmarking paradox. When we estimate our stochastic cost frontier model in equation 3, we effectively impose a common set of parameters a_0, a_i, a_{ij} and a_{ii} (for $i = 1, ..., 3$, $j = 1, ..., 3$ and $i \neq j$. Put differently, all banks for which we estimate the same equation 3 are thereby assumed to share the same production technology. For example, two efficient banks with the same input-output combinations will have the same total cost. And for both banks, an increase in one of the inputs will have the same impact on total cost. Hence, all banks that operate under the same frontier are assumed to share the same production technology, as characterized by the same transformation function (for a more formal discussion, see the Appendix).

In Figure 1, we illustrate this with an example where we estimate a simple cost frontier with two inputs (X_1, X_2) and a single output (Y) for two countries ($f = 1, 2$). In the graph, we compare country-specific frontiers with a pooled frontier and a meta frontier, respectively.

[14] For the profit model, let $\varepsilon_{kt} = \nu_{kt} - u_{kt}$. A firm specific cost efficiency estimate PE_{kt} of bank k at time t is given by the mean of the conditional distribution of -u_{kt} given ε_{kt}, or $PE_{kt} = E[\exp(-u_{\kappa\tau})|\varepsilon_{\kappa\tau}]$.

Figure 1: Meta cost frontier and pooled cost frontier



First, imagine a bank from country $f = 1$ that is located in E. Compared to its own country-specific frontier, this bank's efficiency TE_{kt} is $(E0/B0)^{-1}$. Compared to a pooled frontier, it is $(E0/C0)^{-1}$, somewhat higher. However, a look at Figure 1 reveals that in country $f = 1$ it is possible to produce the same output with lower inputs. In fact, meta efficiency is $(E0/A0)^{-1}$.[15]

Now suppose the bank located in E is from country $f = 2$. In that case, TE_{kt} is $(E0/D0)^{-1}$. Pooled frontier efficiency is now lower, at $(E0/C0)^{-1}$. But we know that the available production technology in the home country does not allow any bank in country $f = 2$ to reach this frontier. Meta efficiency is therefore actually lower, and again at $(E0/A0)^{-1}$. The difference with the first example is that much of the meta efficiency is now caused by the large technology gap ratio $(D0/A0)^{-1}$.

Thus, dependent on the location of the country-specific frontiers and the technology gap ratio we may overestimate the efficiency of some banks and underestimate the efficiency of other banks. Importantly, if there is a single efficient (meta) frontier, we expect the technology gap ratios to be one in all countries.

What is left is an approximation of the meta-frontier $f_o(w_{kt}, y_{kt}, z_{kt})$. In finding this meta-frontier, we rely on the data generation mechanisms from each

[15] We can rewrite this as $TE_{kt} \cdot TGR_{kt} = (E0/B0)^{-1} \cdot (B0/A0)^{-1} = (E0/A0)^{-1}$.

of the N groups. Therefore, the metafrontier is entirely based on the N group frontiers. We therefore solve:

$$\begin{aligned} &Min.M_{kt} = \sum_{t=1}^{T} \sum_{n=1}^{N} \left[f_o\left(w_{kt}, y_{kt}, z_{kt}\right) - f_n\left(w_{kt}, y_{kt}, z_{kt}\right) \right]^2 \\ &s.t.: \;\; f_n\left(w_{kt}, y_{kt}, z_{kt}\right) \geq f_o\left(w_{kt}, y_{kt}, z_{kt}\right) \end{aligned} \tag{5}$$

For our translog cost (profit) model, this amounts to finding the set of parameters for which the meta profit frontier is always below (above) the N group frontiers.[16]

Summing up, we have now developed a framework with which we can compare the efficiency of banks in N groups, without having to assume that they operate under a single, identical frontier. Before we apply this framework to compare banks operating under 15 country-specific frontiers, we first discuss our data and the variables we use to estimate our profit and cost model.

4 Data

This study comprises bank's balance sheet as well as profit and loss account data of 15 European banking markets over the period 1993-2004. The data were compiled from the International Bank Credit Analysis Bankscope Database. As explained above, heterogeneity can affect stochastic frontier analyses in different ways. Since our aim here is to compare similar banks that operate in different markets, we limit our analysis to commercial banks. In order to estimate separate regional and common frontiers, the sample selection requires us to consider only those countries, for which a sufficient large number of observations is available.[17]

We analyze banks from 15 countries, most of which are at present member

[16] Estimating meta-frontiers can be precarious (cf. Battese et al. (2004). We minimize the squared distance to the frontier, because we want the meta-frontier to envelope tightly around the N group frontiers. Taking for example the absolute deviation would ceteris paribus result in a less tight envelope. We use the quasi-Newton BFGS algorithm. An advantage of this algorithm is the fact that in the line search, the Hessian matrix is replaced with a matrix that is always positive definite (cf. Judd (1999)). We estimate over all parameters, but fix the coefficients of those variables with the highest variance inflation factors to their pooled frontier values if necessary (in this case for 4 out of 35 variables).

[17] We select independent commercial banks. As a rule of thumb, we include all European countries for which we have at least 200 observations. An exception is Sweden, for which we have only 28 observations. However, Sweden's banking market is highly integrated with that of Norway. Therefore, we estimate a joint frontier for Sweden and Norway. Excluding Sweden from our analysis does not affect our results.

Table 1: Variables, Definition and Summary Statistics, 1993-2004

Variable	Definition	Mean	Std Dev	Min.	Max.
TC	Total cost	672.854	1811.549	0.300	20086.500
PBT	Profit before taxes	238.815	787.584	0.100	12293.700
Y_1	Loans	18012.140	52902.540	0.100	619690.800
Y_2	Investments	15239.140	41809.260	0.100	755379.900
Y_3	Off-balance sheet items	22362.400	195089.100	0.100	5358907.000
W_1	Labor price	0.081	0.922	0.000	66.885
W_2	Financial capital price	0.012	0.009	0.000	0.220
W_3	Physical capital price	1.895	2.381	0.236	29.169
Z	Equity/assets	6.921	6.610	0.002	96.852
Assets	Total assets	36055.080	98530.220	1000.200	1257998.000

N=9,544. All variables are denoted in 1,000s of USD, corrected for inflation

states of the European Union.[18] After excluding all missing and zero observations, we have an unbalanced panel consisting of 9,544 observations for commercial banks belonging to 15 European banking markets. All currency variables are expressed in US dollars and corrected for inflation.

In the literature, the definition of bank inputs and outputs varies across studies and mainly depends on what a researcher pictures a bank to be. This study follows the so-called intermediation approach, which views a bank as an intermediary between depositors and borrowers. Accordingly, bank outputs are defined as loans (Y_1) and investments (Y_2), and off-balance sheet items (Y_3). More precisely, loans comprise commercial and industrial, real estate, consumer, and other outstanding credits. Investments aggregate securities, equity investments, and other investments. Off-balance sheet items refer to credits and other guarantees, which are not reported on the balance sheet. Concerning input prices, the price of labor (W_1) equals the total employee expenses scaled by the total sum of assets. Similarly, the price of financial capital (W_2) is measured as the total interest expenses per unit of total assets, and the price of physical capital (W_3) represents all non-interest operating expenses divided by the sum of assets. Finally, the variable equity/total assets (Z) controls for differences in equity capital risk across banks. Banks with lower equity ratios are assumed to be more risky, in line with Mester (1996). In order to estimate profit and cost efficiency scores, we use the total operating cost (TC) and profits before taxes (PBT) as our dependent variables.

Table 1 displays the definition, mean, standard deviation, as well as minimum and maximum values of all the input prices, outputs, and dependent variables.

[18] We also estimated all specifications for only E.U. countries, again without significant differences in results.

5 Results

We start this section by comparing results from our estimations. Next, we discuss the stability of efficiency rankings across single, pooled and meta frontiers. Finally, we look for possible trends in both mean efficiency and technology gap ratios over the period under investigation.

5.1 Technology gaps

For each country in our sample, Table 2 contains efficiency scores for both our profit and cost model. First, we report the pooled efficiency scores, based on estimations of a fixed effect frontier (cf. Greene, 1995), with country-specific fixed effects. Second, we include the efficiency scores that result from estimating country-specific frontiers. Third, we report technology gap ratios and meta efficiency scores that result from enveloping these single frontiers. [19]

Of course, an important caveat applies when comparing these efficiency scores. For each specification, the scores reflect the relative distance to the benchmark. However, as our example in Figure 1 demonstrates, the benchmark may be different for each specification. Still, we can observe some interesting facts when comparing results across specifications. First, as in the example in Figure 1, pooled efficiency scores can be both lower and higher than single frontier scores. In most cases, however, they are lower - especially for the cost efficiency scores. Overall, the scores resulting from the common or pooled frontier seem to underestimate the cost and profit efficiency levels for the sample countries. Our results suggests that the assumption of "one" pooled frontier technology induces a strong bias in cross-country comparisons and may yield misleading results. This view is supported by prior findings in the literature (cf. Bikker, 2002, and Dietsch and Lozano-Vivas, 2000). [20]

A second observation concerns the spread in efficiency scores. Pooled scores tend to have a higher spread. For the cost model, minimum pooled scores tend to be lower. [21] Taken together, this points into the direction of our earlier

[19] Technology gap ratios are calculated as the ratio of expected cost (profit) from the single frontier estimation and the expected cost (profit from the meta frontier estimation. For the cost model, the latter is calculated as $tc_{kt}^{m*} = M_{kt}^{*} + tc_{kt}^{*}$, where M_{kt}^{*} is the predicted value from estimations of equation 5 and tc_{kt}^{*} is expected cost from the single frontier estimation. Hence, $TGR_{kt} = \frac{tc_{kt}^{*}}{M_{kt}^{*}+tc_{kt}^{*}}$.

[20] All models were estimated in Limdep 8. All specifications were estimated with truncated normal distributions and converged properly.

[21] Minimum scores for the pooled specifications are the same for all countries. This can be the result of using a fixed effects estimator (see Greene, 2005, for a discussion). We also compared our meta-frontiers to pooled frontiers without fixed effects, in which case results are even more favorable for the former, especially with respect to rank stability.

Table 2: Efficiency Scores and Technology Gap Ratios [TGR]

		Profit efficiency [PE]					Cost efficiency [CE]				
Variable		Mean	SD	Min	Max	ρ	Mean	SD	Min	Max	ρ
Austria (AT)											
pooled	358	0.448	0.176	0.089	0.936	0.613	0.783	0.128	0.512	0.935	0.326
single	358	0.567	0.176	0.189	0.945		0.753	0.126	0.408	0.961	
tgr	358	0.900	0.118	0.325	1.000		0.986	0.041	0.548	1.000	
meta	358	0.509	0.162	0.061	0.917	0.918	0.744	0.134	0.224	0.938	0.997
Belgium (BE)											
pooled	372	0.444	0.215	0.089	0.829	0.652	0.755	0.148	0.512	0.951	0.528
single	372	0.641	0.185	0.388	0.963		0.918	0.024	0.787	0.969	
tgr	372	0.945	0.096	0.299	1.000		0.987	0.047	0.582	1.000	
meta	372	0.609	0.192	0.116	0.963	0.960	0.907	0.049	0.527	0.960	0.850
Denmark (DK)											
pooled	321	0.463	0.195	0.089	0.852	0.301	0.818	0.067	0.597	0.969	0.519
single	321	0.704	0.100	0.645	0.971		0.977	0.006	0.948	0.991	
tgr	321	0.940	0.079	0.286	1.000		0.999	0.003	0.974	1.000	
meta	321	0.662	0.107	0.185	0.958	0.762	0.975	0.007	0.947	0.985	0.927
France (FR)											
pooled	1808	0.409	0.238	0.089	0.897	0.812	0.747	0.145	0.512	0.980	0.823
single	1808	0.504	0.237	0.127	0.925		0.725	0.137	0.444	0.976	
tgr	1808	0.953	0.065	0.217	1.000		0.995	0.014	0.770	1.000	
meta	1808	0.481	0.229	0.028	0.905	0.986	0.722	0.137	0.342	0.974	0.997
Germany (DE)											
pooled	1133	0.388	0.244	0.089	0.910	0.845	0.745	0.143	0.512	0.982	0.810
single	1133	0.445	0.242	0.100	0.899		0.849	0.064	0.795	0.986	
tgr	1133	0.973	0.056	0.427	1.000		0.991	0.026	0.697	1.000	
meta	1133	0.433	0.237	0.043	0.893	0.990	0.841	0.069	0.554	0.981	0.927
Greece (GR)											
pooled	282	0.381	0.240	0.089	0.883	0.458	0.754	0.129	0.512	0.940	0.451
single	282	0.930	0.023	0.915	0.980		0.863	0.067	0.694	0.989	
tgr	282	0.908	0.100	0.473	1.000		0.996	0.006	0.961	1.000	
meta	282	0.845	0.095	0.433	0.967	0.295	0.859	0.066	0.677	0.977	0.997
Italy (IT)											
pooled	1193	0.441	0.209	0.089	0.917	0.157	0.761	0.142	0.512	0.969	0.804
single	1193	0.993	0.001	0.993	1.000		0.818	0.091	0.700	0.988	
tgr	1193	0.910	0.132	0.042	1.000		0.995	0.015	0.786	1.000	
meta	1193	0.904	0.131	0.041	0.997	0.024	0.813	0.093	0.639	0.986	0.985
Luxembourg (LU)											
pooled	745	0.438	0.210	0.089	0.916	0.098	0.753	0.124	0.512	0.979	0.708
single	745	0.720	0.015	0.719	0.951		0.809	0.101	0.570	0.971	
tgr	745	0.853	0.083	0.532	1.000		0.995	0.018	0.715	1.000	
meta	745	0.614	0.062	0.382	0.903	0.124	0.804	0.101	0.550	0.971	0.983

Mean, Standard Deviation (SD), Minimum (Min.) and Maximum (Max.) efficiency scores, and pearson correlations compared to single frontiers (all significant at the 1% level).

observations that pooled frontier estimations can lead to a downward bias in efficiency if technology gap ratios are lower than one. In fact, maximum TGR scores of one in Table 2 show that single frontiers are partially tangent to the

(table 2 continued)

Variable		Profit efficiency [PE] Mean	SD	Min.	Max.	ρ	Cost efficiency [CE] Mean	SD	Min	Max	ρ
Netherlands (NL)											
pooled	389	0.479	0.187	0.089	0.891	0.775	0.739	0.141	0.512	0.982	0.393
single	389	0.657	0.187	0.351	0.946		0.715	0.141	0.361	0.954	
tgr	389	0.979	0.057	0.126	1.000		0.975	0.040	0.706	1.000	
meta	389	0.644	0.189	0.098	0.942	0.981	0.698	0.146	0.318	0.920	0.984
Norway (NO)											
pooled	234	0.464	0.207	0.089	0.796	0.600	0.797	0.090	0.537	0.952	0.393
single	234	0.642	0.142	0.526	0.959		0.917	0.049	0.819	0.993	
tgr	234	0.962	0.060	0.604	1.000		0.994	0.006	0.976	1.000	
meta	234	0.618	0.145	0.340	0.959	0.903	0.911	0.049	0.805	0.984	0.990
Portugal (PT)											
pooled	284	0.458	0.196	0.089	0.864	0.557	0.664	0.175	0.512	0.961	0.294
single	284	0.760	0.083	0.471	0.911		0.804	0.068	0.551	0.922	
tgr	284	0.934	0.093	0.366	1.000		0.917	0.102	0.478	1.000	
meta	284	0.710	0.107	0.263	0.906	0.744	0.739	0.107	0.372	0.887	0.641
Spain (ES)											
pooled	1073	0.397	0.246	0.089	0.905	0.216	0.789	0.118	0.512	0.970	0.820
single	1073	0.599	0.072	0.581	0.985		0.833	0.090	0.638	0.982	
tgr	1073	0.908	0.101	0.182	1.000		0.997	0.014	0.765	1.000	
meta	1073	0.543	0.087	0.108	0.973	0.381	0.830	0.091	0.582	0.978	0.989
Sweden (SE)											
pooled	28	0.312	0.278	0.089	0.830	0.540	0.673	0.169	0.512	0.954	0.278
single	28	0.628	0.157	0.526	0.953		0.892	0.059	0.819	0.984	
tgr	28	0.892	0.148	0.325	1.000		0.971	0.033	0.891	1.000	
meta	28	0.557	0.171	0.274	0.911	0.584	0.865	0.062	0.756	0.982	0.860
Switzerland (CH)											
pooled	395	0.444	0.194	0.089	0.896	0.540	0.770	0.118	0.512	0.964	0.610
single	395	0.582	0.167	0.157	0.911		0.860	0.079	0.627	0.974	
tgr	395	0.940	0.091	0.365	1.000		0.993	0.021	0.782	1.000	
meta	395	0.547	0.163	0.082	0.908	0.584	0.854	0.082	0.553	0.973	0.977
United Kingdom (UK)											
pooled	929	0.428	0.225	0.089	0.904	0.648	0.741	0.142	0.512	0.981	0.779
single	929	0.463	0.201	0.113	0.899		0.739	0.130	0.453	0.971	
tgr	929	0.954	0.063	0.316	1.000		0.993	0.015	0.892	1.000	
meta	929	0.443	0.195	0.045	0.876	0.920	0.734	0.130	0.423	0.970	0.995
Europe											
pooled	9544	0.424	0.225	0.089	0.936	0.741	0.757	0.138	0.512	0.982	0.779
single	9544	0.629	0.243	0.100	1.000		0.805	0.122	0.361	0.993	
tgr	9544	0.933	0.094	0.042	1.000		0.991	0.031	0.478	1.000	
meta	9544	0.584	0.230	0.028	0.997	0.988	0.798	0.125	0.224	0.986	0.995

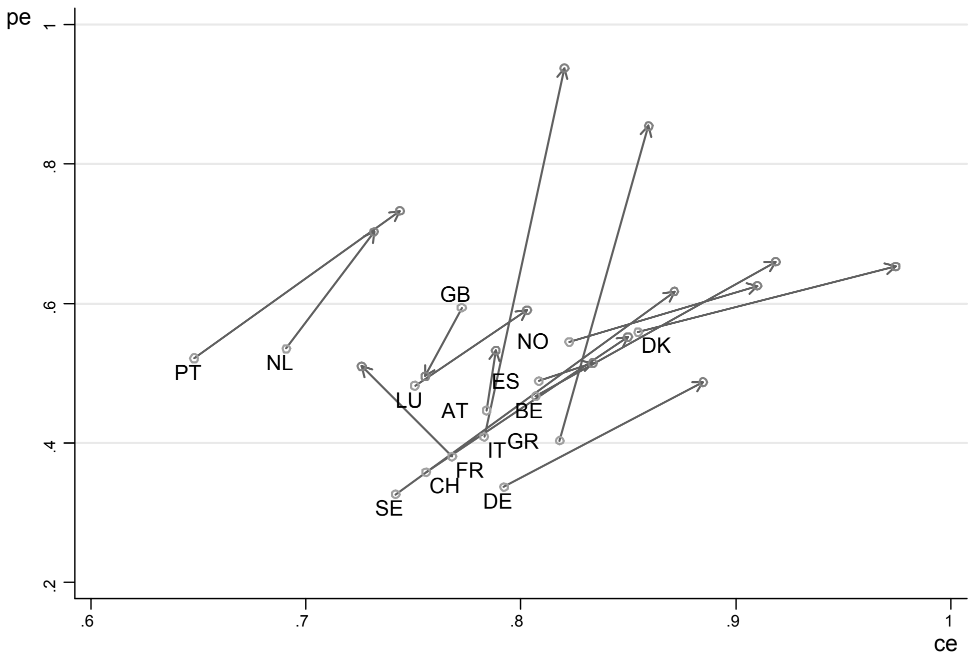
Mean, Standard Deviation (SD), Minimum (Min.) and Maximum (Max.) efficiency scores, and Pearson correlations compared to single frontiers (all significant at the 1% level).

meta frontier in all countries, both for the profit and for the cost model.[22] But average TGRs vary across countries, and are significantly lower than one in many cases.

[22] Battese et al. (2004) found much bigger variations in the technological gap ratios for Indonesian garment firms across different regions.

Finally, Figure 2 compares average pooled and meta efficiency scores, weighted by total assets. The cost and profit efficiency of most Scandinavian banks is significantly underestimated when we estimate a pooled frontier, as reflected by shifts of Norway, Denmark and Sweden to the northeast of Figure 2. Banks in countries with relatively high market concentration experience increases in profit efficiency when they move from a comparison to a pooled frontier to a comparison to a meta frontier (cf. Portugal, the Netherlands, Italy and Greece). On the other hand, British' banks cost and profit efficiency decreases somewhat. German banks' cost and profit efficiency increases, but Germany remains a laggard. French banks cost efficiency decreases when we move to a meta-frontier.

Figure 2: From pooled frontiers to meta-frontiers



arrows point from pooled frontier to meta-frontier results based on mean efficiency scores, weighted by assets

At the very least, our results so far suggest two things. First, with our meta-frontier approach we can compare country-specific frontier estimates. This is an important result, since we can now be critical of pooled frontier estimations, but still arrive at comparable efficiency scores. Second, our analysis suggests that pooled frontiers may not be flexible enough to accomodate the transformation functions of banks in all European countries. Put differently, if we were to place a Swiss, cost efficient bank in e.g. Spain, it is doubtful that it can be as cost efficient as it is now. This too is an important results, since it may provide a partial explanation of the scarcity of cross-border mergers.

In this light, it is not surprising that we find the largest differences for the profit model. It is a common finding in the literature that profit efficiency scores tend to be lower and vary more than cost efficiency scores. Our analysis so far suggests that this may reflect the fact that country-specific circumstances (competition, regulation, etc.) result in different optimal frontiers. In general, the analysis and Figure 2 show that even in a harmonized single European banking market, the observed efficiency levels of banks varies substantially across markets. Additionally, it turns out that European banks do not always have access to the same benchmark technology. Consequently, these findings confirm the view that different technologies might be crucial and should be taken into account when comparing European bank efficiency. At the same time, average technology gap ratios are close to one, proving that differences between country-specific frontiers and a European meta frontier are rather small for the single European banking market.

5.2 Rankings

As mentioned above, comparing absolute efficiency scores across specifications has its limitations. In order to further analyze our results, we therefore turn to efficiency rankings. In particular, we are interested in the stability of efficiency rankings. Our approach here is straightforward: we start from the country-specific efficiency rankings. We build on the premise that any bank that is a star on its home turf, should still outshine its compatriots when compared against a European frontier.

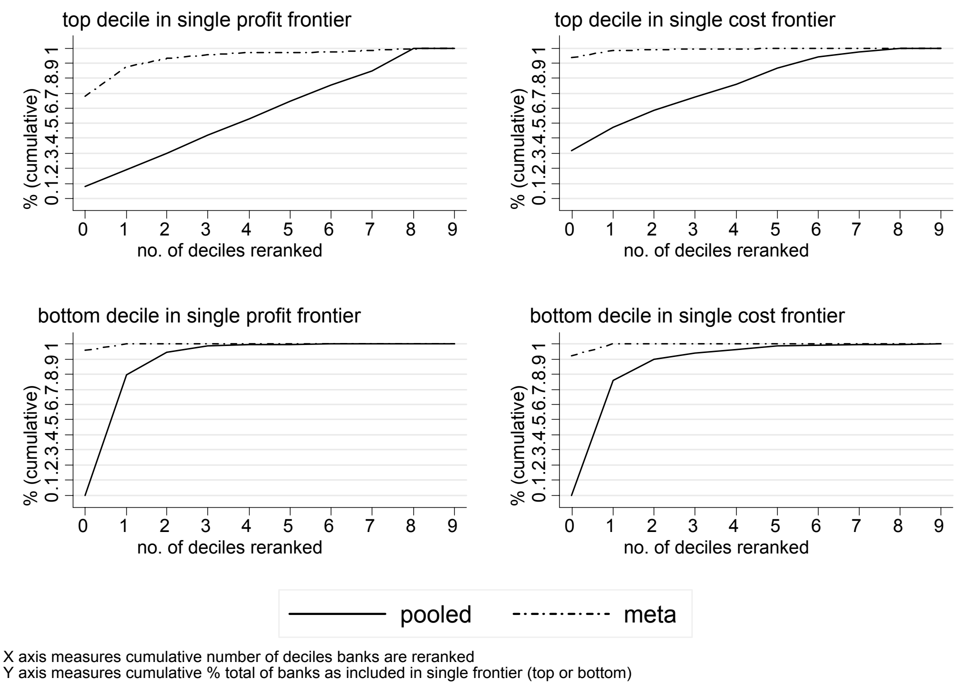
As a first test, in Figure 3, we compare our pooled and meta-frontier rankings with our single frontier rankings. In particular, we want to find out whether different specifications identify the same banks as highly efficient and highly inefficient, respectively.[23] To this end, we rank country-specific, pooled and meta-frontier scores and assign them to ten deciles. What we are interested in is the stability of rankings compared to country-specific results. In the top left part of Figure 3 we ask ourselves the question: how many deciles are banks reranked when we compare their pooled and meta-frontier rankings to country-specific rankings? The lower the slope of the lines in Figure 3, the lower rank stability is.[24] For example, in the top left of Figure 3, we observe that approximately 60% of the banks that are identified as being in the top decile when we estimate country-specific profit frontiers are ranked at most 5 deciles lower when we estimate pooled frontiers. Put differently,

[23] Cf. Bos et al. (2005) for a similar type of analysis.

[24] The graphs in Figure 3 can be read as so-called receiver operating characteristic (ROC) curves: if e.g. pooled frontiers and country-specific frontiers identify exactly the same banks as highly efficient, then the (cumulative) number of deciles banks are reranked is zero, and the straight lines in Figure 3 are vertical at the origin, before becoming horizontal.

40% of the country-specific top performers are measured as below average when we estimate a pooled frontier. We observe that at both ends of the distribution, meta-frontier scores have much higher rank stability then pooled frontier scores.

Figure 3: Stability of Rankings



Unfortunately, Figure 3 does not tell us much about country-specific results. In Table 2, we therefore compare rank correlations ρ per country.[25] For most countries, we find that rank correlations between the single and meta rankings are significantly higher than those between the single and pooled rankings. There are some exceptions however. For the profit model, banks in Greece, Italy, Luxembourg and Spain have very low rank correlations. For Greece and Italy, rank correlations are even lower for the meta scores than for the pooled scores. For the cost model, results are more convincing across the board. Again, this is an important result, which sheds light on our (in)ability to arrive at comparable and robust efficiency scores.

Finally, we take our analysis one step further and study rank stability across all decile combinations. Table 3 in the Appendix contains transition matrices for our profit and cost models. For example, the probability that a bank that is in the highest (100) decile for the single profit frontier rankings is in the lowest

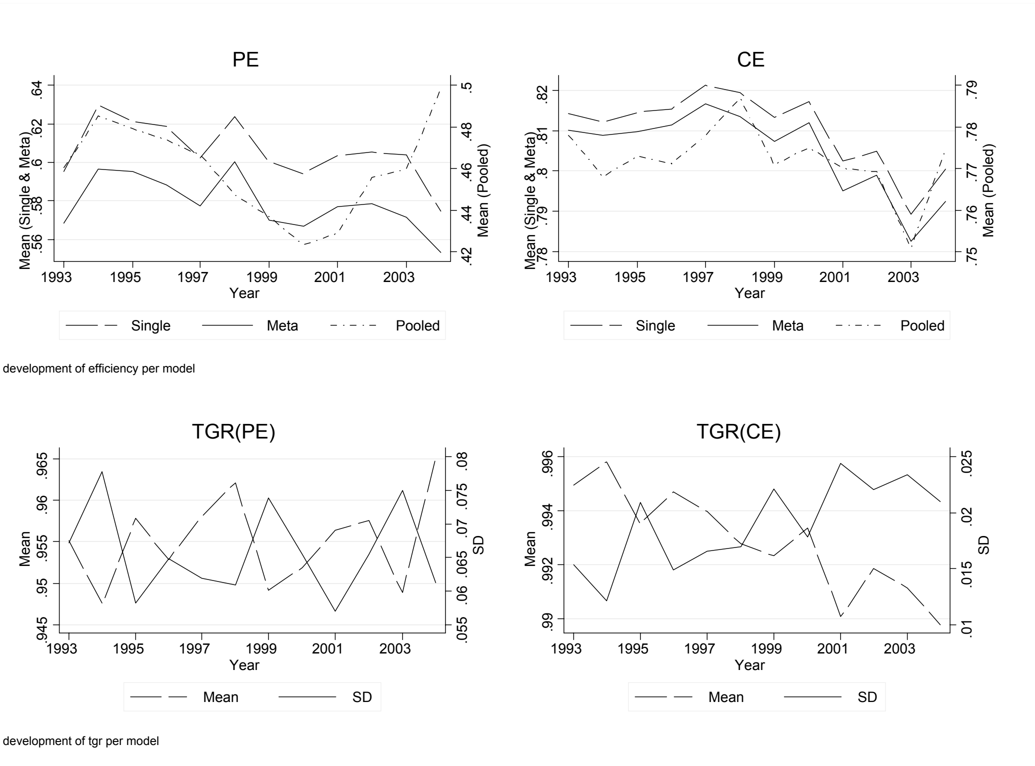
[25] Correlations shown are Spearman rank correlations. Kendall rank correlations yield qualitatively similar results.

decile (10) for the pooled profit frontier rankings is 7.45%. Table 3 shows us that - compared to single frontier rankings - our meta frontier rankings are not just more stable for top decile and bottom decile banks than our pooled frontier rankings. In fact, rank stability is higher across the board, as shown by high probabilities across the diagonal.

5.3 Trends

Finally, we wish to find out whether the efficiency scores and technology gap ratios show a particular trend during the period 1993-2004.[26] First, we ask whether mean efficiency has increased since 1993.[27] If the creation of the single European banking market has increased competition, we expect higher cost efficiency and lower profit efficiency. Figure 4 shows that cost efficiency has decreased over the period under consideration. Profit efficiency on the other hand does not show a steady increase or decrease. Rather, it appears to move with the economic cycle.

Figure 4: Trends in efficiency and TGRs



For both models, mean efficiency scores move in the same direction for different specifications. An exception is mean pooled profit efficiency, which increase sharply after 2001, when single and meta scores decrease.

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[26] Remember that we estimate our models with a trend as explained in equation 3. However, we do not impose a trend on υ_{kt} or on our TGRs.
[27] As in Figure 2, mean efficiency scores are weighted by total assets.

So far, our trend analysis does not show convergence in the European banking market. However, a more appropriate way to study the latter is by looking at mean TGRs and the standard deviation of TGRs. If Europe's banking markets have become more alike over our 11 year period under consideration, we expect an increase in mean TGRs and a decrease in the spread of TGRs. For the cost model, we observe the exact opposite: mean technology gap ratios have decreased over time, and the standard deviation of TGRs has increased. For the profit model, we again observe no clear trend. However, we do note that mean profit TGR and its standard deviation move in opposite ways. The standard deviation tends to be high when averege TGRs are low, and vice versa. In part, this reflects the fact that there are always banks that operate tangent to the meta-frontier.

Summing up, we indeed find evidence in favor of the existince of a single European banking market, characterized by common (meta) cost and profit frontiers. However, our results strongly support the view that traditional efficiency techniques based on pooled frontier efficiency scores tend to underestimate cost and profit efficiency levels and may wrongly identify very efficient and very inefficient banks. Also, we find little evidence of a convergence trend. Rather, single frontiers appear to be partially tangent to the meta-frontiers from the beginning of the single banking market.

6 Conclusion

The creation of the Single Market for Financial Services on January 1, 1993 was expected to foster cross-border competition and increase financial integration. Despite the enormous potential, the immediate effect of these initiatives has been limited to increased consolidation of banks and banking markets at the local level (Berger et al., 2000). For this reason, it is of topmost interest for policy makers, regulatory and monetary authorities, as well as expert practitioners and researchers, to know more about the true underlying differences or similarities of bank performance and efficiency among European countries in order to better adjust to the new environment, to undertake strategic decisions, to benchmark banking institutions performance, and to prepare for increasing competition in domestic as well as cross-border markets. Most previous work on international efficiency banking comparisons usually defines national or common frontiers by pooling banks from all European countries. However, since efficiency measurement is a relative concept these approaches do not settle the issue of efficiency differences among the banking industries across countries.

This paper takes a systematic attempt to provide 'truly' comparable efficiency scores for each European banking industry. Although this paper does not fully resolve all concerns about cross-border comparisons, it applies a new method for comparing European bank efficiency, while taking into account the fact that banks in different countries may not operate under the same frontier due to differences in technology, competition, supervision, etc. First, the paper evaluates the efficiency levels of banking industries by estimating country-specific and pooled cost and profit frontiers. Second, we identify and estimate a meta-frontier that is designed to encompass all the components of the country-specific frontiers for the banks that operate under different technologies. Therefore, the meta-frontier approach allows for a fair comparison of different banking systems by benchmarking the nature of the production process for an average bank in each country using the technology that is available to the industry as a whole.

Overall, the empirical results suggest that average cost and profit efficiency varies considerably across Europe. Our meta-frontiers result in efficiency scores and rankings that are much more in line with country-specific results. At the same time, the small technology gap ratios suggest that we are not far removed from a single European profit or cost frontier. Whether individual banks can benefit from the current situation remains to be seen. Based on our results, banks that very efficient in their home country may have a hard time being equally successful abroad. Seen in this light, our analysis may help explain the limited number of cross-border mergers that have taken place in the European banking market since the inception of the single banking market. Our profit model results may imply that local competition is an important determinant of bank efficiency.

Our results shed light on some important policy debates. First, the analysis presented here is a motivation for further research into the importance of entry barriers and the significance of cross-border price elasticities. Second, with these results we can be somewhat critical of the idea that countries need large banks in order to compete European wide. Third, and most important, our results suggest that - at least initially - the expected welfare gains from an increase in cross-border mergers may be very limited. Even when efficient banks take over inefficient banks, efficiency may be very hard to export since it appears to have at least some local determinants.

Finally, we wish to point out an important area for further research. In this paper, we have purposely focused on a cross-country comparison of independent commercial banks. The reason for this limitation in scope, is the fact that we aimed to compare banks with a relatively homogenous production set that are in many ways as comparable as possible. Although our meta-frontier methodology constitutes a way of arriving at comparable efficiency scores for banks that do not operate under the same "local" frontiers, it does not tell us how to select banks that have a common production technology. This is a highly relevant question that we aim to return to in future research.

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Appendix

Deriving a Meta frontier

In Figure 1, we graphically illustrated the concept of meta-frontiers for a cost minimization model. Here, we formally derive a meta-frontier for a profit maximization model.

We started out by examining some of the assumptions on which the profit and cost model we have derived above are based. Now we relax one important assumption. As before, we assume that the banks in our sample are comparable, in that they produce the same outputs using the same inputs (albeit not necessarily in the same proportions). Put differently, we do not assume that the banks in our sample compete, but ensure that they could in principle. We do so by only considering banks with identical productions sets.[28] In addition, we still assume that all K banks in our sample share the same functional form. What we no longer assume is that this functional form captures the same production technology. More precisely, banks can now maximize profits (minimize costs) using different transformation functions T.

Suppose that for a total of K banks, we have separate transformation functions T for N different groups. Our Lagrangian for group n of N then becomes:[29]

$$L\Pi_n \;=\; P'Y - W'X - \lambda T_n(\bullet) - \theta H(P,Y,W,Z) \;=\; 0 \tag{6}$$

And the optimal profits are given by:

$$\Pi_n^* \;=\; P_n^*(Y,W,Z)'Y - \; W'X_n^*(Y,W,Z) \;=\; \tilde{\Pi}_n\,(Y,W,Z) \tag{7}$$

For our sample of K banks, we are left with N optimality conditions. For $\sum_{n=1}^{N}$:

$$\Pi_n^* = P_n^*(Y,W,Z)'Y - W'X_n^*(Y,W,Z) = \tilde{\Pi}_n(Y,W,Z) \tag{8}$$

We can then express optimal profits as :

$$\begin{aligned} &\Pi_o \;=\; P_o(Y,W,Z)'Y - \; W'X_o(Y,W,Z) \;=\; \tilde{\Pi}_0\,(Y,W,Z) \\ &s.t.\, P_o(Y,W,Z)'Y - \; W'X_o(Y,W,Z) \;\geq\; P_n^*(Y,W,Z)'Y - \; W'X_n^*(Y,W,Z) \end{aligned} \tag{9}$$

We follow Battese et al. (2004) and define this metafrontier as "a deterministic parametric function (of specified functional form) such that its values are no smaller than the deterministic components of the stochastic frontier production functions of the different groups involved, for all groups and time periods" (p. 3, Battese et al., 2004).

[28] Note again that we do not make any assumptions with respect to the weights of the outputs and inputs in this production set.

[29] For ease of notation, we drop the subscripts. So P should now be $P_{kt,n}$ and so on.

Next, we present our translog profit model for group n as:

$$pbt_{kt}(w, y, z) = f_n(w, y, z) + v_{kt} - \upsilon_{kt} \quad (10)$$

We can now decompose bank-specific inefficiency for a bank k in group n as follows. We start by rewriting equation (10):

$$pbt_{kt}(y, w, z) = \frac{f_0(w, y, z)}{f_n(w, y, z)} \cdot f_n(w, y, z) + v_{kt} - \upsilon_{kt} \quad (11)$$

where $f_o(w_i, y_i, z)$ refers to the metafrontier profit function. Then we identify the two components of the inefficiency of bank k in group n. Recall that $\nu_{kt} \sim N(0, \sigma_\nu^2)$. First, we identify bank k's technical efficiency (TE):[30]

$$TE_{kt} = \frac{pbt_{kt}(y, w, z)}{f_n(w, y, z) + v_{kt}},\ 0 < TE_{kt} \leq 1 \quad (12)$$

Second, we identify bank k's technology gap ratio (TGR):[31]

$$TGR_{kt} = \frac{f_n(w, y, z) + v_{kt}}{f_o(w, y, z)}\ ,\ 0 \leq TGR_{kt} \leq 1 \quad (13)$$

This is the ratio of the frontier profit for a bank in group n compared to that bank's maximum profit that is possible under the metafrontier function. Hence, TGR values range between zero and one, where the latter results if the single frontier is tangent to the meta frontier. Combined this results in bank k's meta efficiency (ME):

$$ME_{kt} = \frac{pbt_{kt}(w, y, z)}{f_o(w, y, z)} = TE_{kt} \cdot TGR_{kt}\ ,\ 0 \leq ME_{kt} \leq 1 \quad (14)$$

Thus, the meta-efficiency scores are the technical efficiencies of each particular bank in different countries corrected by the technological gaps of the banks in a given country relative to the technology available to the industry as a whole.

Testing stability with transition matrices

In table 3 we report transition matrices with unconditional transition probabilities. Again, our benchmark consists of the country-specific decile memberships. As a result, if rank correlation is 1 between e.g. country-specific frontiers and meta-frontiers, then we obtain a transition matrix with only zeros, except for the values 100 across the diagonal. We observe that rank stability across all deciles is highest for the meta-frontier models.

[30] Recall that empirically, profit efficiency is measured as $PE_{kt} = \exp(-u_{\kappa\tau})$.

[31] For the cost model, $f_o(w, y, z) \leq f_n(w, y, z)$ and $TGR_{kt} = \frac{f_o(w,y,z)}{f_n(w,y,z)}$, $0 \leq TGR_{kt} \leq 1$.

Table 3: Transition probabilities

pe pooled	10	20	30	40	50	60	70	80	90	100	Total
10	30.55	12.72	14.05	8.51	7.47	6.21	5.25	5.25	5.10	4.88	100
20	30.29	11.11	13.62	9.14	8.24	5.38	6.45	6.27	5.02	4.48	100
30	19.62	7.87	10.60	11.75	11.33	9.97	6.93	7.45	7.87	6.61	100
40	13.22	4.51	12.59	12.38	10.07	11.33	11.02	9.13	8.18	7.56	100
50	8.18	4.40	11.22	12.37	12.26	13.10	12.37	9.33	8.81	7.97	100
60	7.43	3.77	9.42	11.73	10.68	12.15	11.52	12.25	11.31	9.74	100
70	6.93	3.05	8.72	9.24	13.76	11.45	10.29	12.61	11.76	12.18	100
80	7.97	3.67	6.30	9.86	9.44	12.07	12.07	12.70	12.80	13.12	100
90	9.99	4.00	6.83	7.78	8.73	10.20	12.93	12.51	12.83	14.20	100
100	7.45	2.83	6.30	7.45	8.18	7.76	11.65	13.01	16.16	19.20	100
Total	14.18	5.86	9.99	10.00	9.99	10.00	10.00	10.01	9.99	10.01	100

pe meta	10	20	30	40	50	60	70	80	90	100	Total
10	92.14	6.60	0.21	0.00	0.21	0.00	0.00	0.10	0.42	0.31	100
20	5.88	74.29	13.12	2.31	1.26	0.73	0.63	0.31	0.84	0.63	100
30	0.94	11.82	36.72	32.22	11.82	1.67	1.67	0.84	1.05	1.26	100
40	0.00	3.26	29.13	28.92	21.77	6.20	7.05	2.42	0.74	0.53	100
50	0.21	0.63	14.26	20.65	38.05	15.83	7.65	2.20	0.21	0.31	100
60	0.00	0.84	2.73	6.50	15.93	39.83	23.79	7.02	1.89	1.47	100
70	0.00	0.73	0.94	5.87	8.81	24.84	35.64	15.93	4.82	2.41	100
80	0.00	0.11	0.84	2.00	1.58	7.35	17.12	42.33	22.06	6.62	100
90	0.31	0.52	0.73	0.63	0.31	1.89	3.98	22.43	32.91	36.27	100
100	0.53	1.16	1.47	0.74	0.32	1.58	2.63	6.41	34.98	50.21	100
Total	10.01	10.00	10.02	9.99	10.01	10.00	10.02	10.00	9.99	10.00	100

ce pooled	10	20	30	40	50	60	70	80	90	100	Total
10	32.54	13.74	12.92	9.81	7.77	6.13	6.05	4.01	3.11	3.92	100
20	24.74	14.06	15.08	11.42	7.32	8.78	6.00	5.56	3.95	3.07	100
30	19.29	9.01	15.30	11.22	9.54	9.33	7.65	7.23	6.71	4.72	100
40	11.74	8.07	11.84	13.00	10.06	12.47	10.17	8.60	8.18	5.87	100
50	8.39	6.72	9.97	10.81	11.65	10.91	11.23	9.65	8.71	11.96	100
60	9.13	5.77	8.60	11.02	12.59	10.60	9.76	12.28	11.96	8.29	100
70	8.49	4.82	6.81	8.49	11.43	11.43	12.05	11.32	12.68	12.47	100
80	4.61	3.35	7.54	8.80	11.10	10.05	12.67	14.14	14.76	12.98	100
90	3.89	3.26	6.31	8.73	9.78	10.20	12.20	14.30	13.77	17.56	100
100	3.25	3.14	6.18	7.23	8.60	10.80	12.26	13.52	16.25	18.76	100
Total	12.83	7.18	10.00	10.01	10.00	10.00	10.01	10.02	9.99	9.99	100

ce meta	10	20	30	40	50	60	70	80	90	100	Total
10	85.64	10.27	1.78	0.73	0.42	0.31	0.31	0.31	0.10	0.10	100
20	10.40	76.47	9.77	1.05	0.74	0.63	0.63	0.00	0.21	0.11	100
30	1.47	9.85	65.93	16.46	3.14	0.84	1.05	0.42	0.63	0.21	100
40	0.74	0.53	16.91	52.94	24.89	2.52	0.53	0.63	0.21	0.11	100
50	0.63	1.15	2.41	25.05	54.82	13.63	1.47	0.42	0.31	0.10	100
60	0.31	0.84	0.94	2.20	13.73	66.56	14.26	0.84	0.21	0.10	100
70	0.21	0.42	1.26	0.73	1.26	14.45	66.60	13.30	1.15	0.63	100
80	0.21	0.10	0.42	0.52	0.42	0.73	13.31	68.45	14.99	0.84	100
90	0.32	0.42	0.53	0.21	0.21	0.32	1.16	14.92	72.58	9.35	100
100	0.10	0.00	0.10	0.10	0.31	0.00	0.63	0.73	9.55	88.46	100
Total	10.01	10.00	10.01	10.00	10.00	10.01	10.01	10.01	9.99	10.00	100

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ISSN 1561081-0