Centre for Banking Research
Cass Business School
City University London

WORKING PAPER SERIES

WP 02/11

Bank productivity in the eurozone

Barbara Casu

(Cass Business School, City University London)

Alessandra Ferrari

(School of Economics, University of Reading)

Claudia Girardone

(Essex Business School, University of Essex)

John O.S. Wilson

(School of Management, University of St Andrews)

Bank productivity in the eurozone

Barbara Casu[a], Alessandra Ferrari[b], Claudia Girardone[c], John O.S. Wilson[d*]

[a] Cass Business School, Cass Business School, City University, London, EC1Y8TZ, UK.
[b] School of Economics, University of Reading, Reading, RG6 6UR, UK.
[c] Essex Business School, University of Essex, Colchester, CO4 3SQ, UK.
[d] School of Management, University of St Andrews, St Andrews, Scotland, KY16 9SS, UK.

This Version: 6 July 2011

ABSTRACT

This paper examines the total factor productivity growth of commercial banks in nine eurozone countries over the period 1992-2009. We utilise a parametric metafrontier Divisia index, which allows for technology heterogeneity and the identification of technology gaps among different countries. A series of tests are employed to determine whether there is long run productivity convergence. The results suggest that while technical improvements have certainly taken place, not all countries have taken full advantage of them. The analysis of convergence indicates that all countries are progressively moving towards the best available technology. The speed of efficiency convergence accelerates after the introduction of the single currency, before decreasing after the 2007 crisis.

JEL Codes G21; G28; G32; D24; C16; C23.

Keywords: European Banking; Productivity Change; SFA, Metafrontier; Convergence.

***** Corresponding Author. Tel.: +44 1334 462803; fax: +44 1334 462812.
Email addresses: b.casu@city.ac.uk (B. Casu), a.ferrari@.reading.ac.uk (A. Ferrari), cgirardone@essex.ac.uk (C. Girardone), jsw7@st-andrews.ac.uk (J.O.S. Wilson).

Bank productivity in the eurozone

1. Introduction

Since the passing of the First Banking Co-ordination Directive in 1977, EU legislation has been directed towards creating an integrated and competitive European banking system.[1] The 1989 Second Banking Coordination Directive sought to enhance competition by establishing EU-wide recognition of single banking licences. The 1992 Maastricht Treaty created the European Union and led to the establishment of the euro currency and the European Central Bank in 1999.[2] Further regulatory initiatives include the Financial Services Action Plan (FSAP) in 1999, which introduced a range of regulatory actions designed to harmonise the EU financial services. In 2005, the EU White Paper on Financial Services Policy (2005-2010) re-emphasised the aim to achieve a fully integrated Single Market in financial services.

The aforementioned regulatory changes were aimed at fostering integration by removing entry barriers and promoting competition, efficiency and productivity growth in the EU banking industry. Evidence suggests that there has indeed been increased entry of foreign

---

[1] Early EU regulatory developments that have influenced the competitive environment under which EU banks operate include the 1985 White Paper on the Completion of the Internal Market and the 1986 Single European Act.

[2] Exchange rates between the national currencies were fixed in 1999, and were replaced by the euro by July 2002.The 11 eurozone countries originally participating in the Economic and Monetary Union (EMU) are the following: Austria, Belgium, Finland, France, Germany, Ireland, Italy, Luxembourg, Netherlands, Spain, and Portugal. On July 2000 the conversion rates between the euro and the Greek drachma were set as Greece fulfilled the conditions for joining the EMU. Since then, five more countries have adopted the euro: Slovenia on 1 January 2007, Cyprus and Malta on 1 January 2008, Slovakia on 1 January 2009 and Estonia on 1 January 2011.

banks; cross-border mergers and acquisitions; enhanced competition and price convergence in many market segments. The growth of cross-border banking within the EU however has had implications for competitive pressures facing banks, and also for supervision. During the financial crisis of 2007–2009, the actions taken by member states to ensure stability may have slowed down the progress of integration (ECB, 2011). This has encouraged the European Commission and European Parliament to re-design cooperation between national regulatory authorities and bring coherence to the supervision of cross-border banking groups. These efforts culminated (in September 2010) in the establishment of a European System of Financial Supervisors (ESFS) and a European Systemic Risk Board (ESRB).

Economic theory suggests that deregulation should stimulate productivity growth, via the general advancement of production technology and the efficiency improvements of individual firms. The positive impact of regulatory reforms on the technology of production is typically based on two arguments: (i) the reduction of regulatory costs will decrease the cost of producing a given level of output; (ii) regulatory reforms usually reduce restrictions on activities, thereby offering the opportunity for firms to take advantage of economies of scale and scope. Efficiency improvements (via a reduction in managerial efficiencies and slack) are expected to arise from the increased competitive pressures on incumbent firms (Bartelsman et al., 2008; Syverson, 2011).

The extent to which empirical evidence supports these theoretical predictions is rather mixed. Some evidence reports improvements in productivity following financial reforms, while other contributions suggest little, no, or even negative productivity growth (Mukherjee et al., 2001, Kumbhakar and Sarkar, 2003; Tirtiroglu et al., 2005). Furthermore, dis-entangling the sources of productivity growth (via technological progress, scale and scope economies and regulatory and supervisory reforms) has proved to be a difficult task.[3]

[3] There is still only limited cross-country empirical evidence on the type of regulatory and supervisory reforms

It is against this background that we seek to assess the productivity growth (and its sources) of commercial banks located in nine eurozone countries (Austria, Belgium, France, Germany, Greece, Italy, Netherlands, Portugal and Spain) over the period 1992 to 2009. By restricting the analysis to the eurozone, our research allows us to assess whether the theoretical "level playing field" created by the single market and the introduction of the single currency enabled banks in different countries to access the same best available technology (or whether national borders still segment the technologies banks can access). Specifically, we aim to address the following research questions: (i) did the creation of a single market for financial services foster bank productivity growth?; (ii) did banking systems benefit in a similar way from EU deregulation?; (iii) what are the main drivers of productivity change? (iv) to what extent does EU bank productivity converge?

To address these questions, we conduct an empirical analysis which centres on the estimation of Divisia indices of Total Factor Productivity (TFP) and related components, based on the estimation of stochastic efficiency frontiers. This is followed by an investigation of convergence of efficiency and TFP.[4] Our contributions to the literature are manifold. First, unlike most of the existing literature, we recognise the heterogeneous nature of banks across countries, and consequently conduct the empirical analysis in the context of a metafrontier framework (Battese et al., 2004; O'Donnell et al., 2008). We then propose a novel measure of productivity change by estimating Divisia indices in a metafrontier framework. To the best of our knowledge, we are the first to adopt this approach to estimate TFP. In addition, we consider the dynamic characteristics of productivity changes over a comparatively long

that promote bank productivity growth and financial sector stability simultaneously (Delis et al., 2011).

[4] There are alternative ways to measure TFP change such as for example the Malmquist index (Malmquist, 1953) based on Data Envelopment Analysis (DEA). For a general overview of the alternative methodological approaches to efficiency and productivity measurement, see, for instance, Fried et al. (2008).

sample period (1992 – 2009), which encompasses the majority of the regulatory changes detailed above, from the signing of the Maastricht Treaty till recent times. Finally, we assess whether banking sectors in eurozone countries are converging towards the use of the best available technology. This is done via the construction of a catch-up index, and a variety of tests (including Augmented Dickey Fuller (ADF), β and σ-convergence tests) of the efficiency and metaefficiency of the countries in our sample.

Key findings from the empirical analysis are as follows. In the estimation of single country frontiers, the results suggest that all banking industries experienced increases in total factor productivity (TFP) over the sample period. These increases appear to have been primarily driven by technical change. The metafrontier analysis confirms our central finding that TFP has improved over time. However these findings vary across countries, with only a few eurozone banking systems experiencing a sustained improvement in TFP over the entire period. At an aggregate level, improvements in technology appear to have resulted in some banking industries gaining while others seem to be lagging behind, especially since the introduction of the single currency in 1999. Finally, our results suggest that there has been some convergence toward best practice technologies over the sample period. This is particularly evident in the aftermath of the introduction of the euro, but prior to the onset of the financial crisis in 2007.

To summarise, our results suggest that the creation of a single market for financial services has fostered bank productivity growth (via improvements in technology), but that the benefits are dispersed across different banking systems. There appears to have been some convergence toward EU-level best practice technologies prior to the onset of the financial crisis, but this has slowed since. The results of the study are of interest to individual and supra-national government agencies that are tasked with monitoring the performance and integration of the banking industry in the eurozone.

The remainder of this paper is structured as follows. Section 2 reviews relevant literature. In Section 3 the specification of the models used in the empirical analysis are described. Section 4 presents the dataset and variables. The results of the empirical investigation are discussed in Section 5, while Section 6 summarises and concludes.

2. Literature

There is a vast body of research utilising a variety of parametric and non-parametric approaches to investigate the determinants and components of bank efficiency.[5] Many studies measure technical and cost efficiency and, to a lesser extent, revenue and profit efficiency, productivity change and growth. Total factor productivity (TFP) growth measures the productivity improvements generated from technical progress and changes in efficiency. This has been a commonly used indicator of the role of technology in determining input productivity.

Productivity growth has been rather slow in the US commercial banking industry during much of the 20th century (Humphrey, 1992; Bauer et al., 1993; Wheelock and Wilson, 1999; Stiroh, 2000; Alam, 2001; Berger and Mester, 2003; Tirtiroglu et al., 2005). Empirical evidence with regard to these issues for banking industries in Europe is rather mixed. Altunbas et al. (1999) find that technical change has systematically reduced European banks' total costs during the 1990s. Battese et al.'s (2000) study of Swedish banks finds that technical change became exhausted with 'average' banks catching up with industry best practice. Casu et al. (2004) estimate productivity change in European banking during the 1990s to find that some countries benefited from productivity growth while others did not.

[5] Berger and Humphrey (1997) review early evidence for US and European banking. Recent literature is reviewed in: Berger (2007); Goddard et al. (2007); Hughes and Mester (2010).

Examples of mixed or unfavourable outcomes of deregulation were found in Portugal (Mendes and Rebelo, 1999; Canhoto and Dermine, 2003) and Spain (Grifell-Tatje and Lovell, 1996, 1997; Lozano-Vivas, 1998; Kumbhakar et al., 2001). Fiorentino et al. (2010) analyse whether consolidation and privatization fostered productivity growth among Italian and German banks during the period 1994-2004. The authors find improvements in productivity in both countries (albeit that there was faster growth in Italy). Outside the US and the EU, the impact of deregulation is often found to be favourable to productivity growth, as in Australia (Avkiran, 2000; Sturm and Williams, 2004), Turkey (Isik and Hassan, 2003), Thailand (Leightner and Lovell, 1998), and Korea (Gilbert and Wilson, 1998).

These conflicting results of productivity estimates across countries are often unexplained by the existing bank efficiency literature. When banks in different groups (delineated by country, industry segment or ownership type) face different technologies their (production or cost functions) frontiers should be estimated separately. Unfortunately this precludes the possibility of meaningful comparisons among them. The assumption underlying the estimation of efficiency against a common frontier is that all banks in the industry are homogenous and utilise the same technology. If this assumption is not correct it will result in biased estimates of efficiency and productivity. Koetter and Poghosyan (2009) identify two main types of systematic differences across and within national banking markets. The first type of heterogeneity pertains to the environment in which banks operate and is exogenous to managers, although it affects their choice of available technology. The second type relates to managerial choices and therefore affects efficiency; that is the ability to attain the optimum benchmark rather than the shape of the efficient frontier.

A handful of recent studies highlight the importance of accounting for cross-country heterogeneity (Bos and Schmiedel, 2007; Kontolaimou and Tsekouras, 2010). Our study augments this recent strand of literature by employing the metafrontier approach (Battese et al., 2004; O'Donnell et al., 2008) to account for technological differences among commercial banks in different EU member states within the eurozone.

The degree of convergence towards best practice technologies by banks in different countries over time is to some extent driven by the level to which barriers to such convergence exist. Evidence suggests that despite legislative change and a variety of policy measures to promote integration in European banking, by the end of the 2000s there were still barriers to the creation of a fully integrated European Single Market in banking and financial services (Gropp and Kashyap, 2009; Casu and Girardone, 2010). Barriers to integration include a lack of consumer trust and confidence; local banks' access to private information about borrowers' creditworthiness; and the bundling of financial services. While there is a general view that competition in EU banking has increased over the last decade or so, it is questionable whether this is reflected in any trend towards the convergence of bank productivity across EU countries. Variations in productivity may still exist due to differences in the intensity of competition in specific banking industries; differences between countries in the nature of the business cycle; and in managerial practices. Gropp and Kashyap (2009) propose a new test of integration based on convergence in banks' profitability (return on assets or ROA), based on the assumption that in equilibrium (with well functioning markets) the expected returns of comparable assets in an economy should be similar. Overall, they conclude, banking markets in Europe appear far from being integrated. A robust alternative to using banks' profitability is to check for convergence in banks' profit or cost efficiency. In this context, Casu and Girardone (2010) utilise dynamic panel methods to explore the extent to which EU bank efficiency is moving toward a common best practice. The results suggest that while there is some evidence of convergence of efficiency levels towards an EU average, there is no evidence of an overall improvement of efficiency levels towards best practice.

3. Empirical methodology

This study examines the evolution of productivity measured by total factor productivity (TFP) Divisia index for banks operating in nine countries in the euro area. It also analyses to what extent changes in productivity vary across countries and over time. Selected convergence tests are carried out so that to allow us to speculate on the progress of European integration. This section presents a discussion of the empirical methods adopted in this study. Section 3.1 describes the framework to estimate country-specific frontiers and Divisia indices. Section 3.2 explains the estimation of the metaefficiency frontiers and introduces the computation of metafrontier Divisia indices. The analysis of convergence is considered in Section 3.3.

3.1. Country-specific frontiers: SFA and Divisia index

From an input minimization perspective, an efficiency frontier is defined as the minimum level of input(s) for a given level of output(s). The efficiency of a firm is measured as a radial distance D from the frontier such that D = 1 when the firm is fully efficient, and D>1 if otherwise.

The stochastic cost frontier models a cost function with a composite error term, made up of two separate, although jointly estimated, components: noise v_{it} ~N(0, σ^2) and inefficiency u_{it} (Aigner et al., 1977; Meeusen and Van den Broek, 1977). There are several possible theoretical distributions for the inefficiency component. This study follows a general-to-specific criterion, and utilises a parametric Likelihood Ratio (LR) test to choose between nested models, and the non-parametric Akaike criterion when these are non-nested.[6]

[6] The most general distribution is a truncated normal with variable mean, which nests the truncated normal with

The translog function is chosen for our empirical analysis. This comprises three inputs and two outputs as follows:

$$
\begin{aligned}
\ln C_{it} = {} & \alpha_0 + \sum_{m=1}^{2}\alpha_m \ln y_{mit} + \sum_{j=1}^{3}\beta_j \ln w_{jit} + \sum_{m=1}^{2}\sum_{q=1}^{2}\alpha_{mj} \ln y_{mit} \ln y_{qit} + \\
& + \sum_{n=1}^{3}\sum_{j=1}^{3}\beta_{nk} \ln w_{nit} \ln w_{jit} + \sum_{j=1}^{3}\sum_{m=1}^{2}\gamma_{jm} \ln w_{jit} \ln y_{mit} + \\
& + \lambda_1 T + \lambda_2 T^2 + \sum_{m=1}^{2}\theta_m T \ln y_{mit} + \sum_{j=1}^{3}\zeta_j T \ln w_{jit} + eEUR + \sum_{m=1}^{2} e_m EUR \ln y_{mit} + \\
& + \sum_{j=1}^{3} e_w EUR \ln w_{jit} + \sum_{p}^{P}\eta_p E_{it} + v_{it} + u_{it}
\end{aligned}
\tag{1}
$$

In Equation (1) C_{it} is the observed total cost of bank *i* at time *t*. To identify the input and output variables, we follow the intermediation approach (Sealey and Lindley, 1977). The three input prices are: the cost of labour (w_1, calculated as personnel expenses over total assets); the price of deposits (w_2, calculated as interest expenses over customer and short-term funding); and the price of capital and other administrative costs (w_3, given by total administrative and other expenses over total assets).

The output variables are total loans (y_1) and other earning assets (y_2).[7] Summary statistics for the three inputs and two outputs are shown in Table 1. EUR is a dummy variable

constant mean, which nests the half normal. The alternative to these is the exponential, and that requires the use of the Akaike criterion. Details on this can be found for instance in Kumbhakar and Lovell (2000).

[7] Given our long sample period and the need to build consistent time series of the relevant variables, we decided not to include off-balance sheet (OBS) activities as a third output. While we are aware that large banks in most EU countries have broadened their portfolio to offer non-traditional services in recent years, evidence on the

set equal to 1 for the period following the introduction of the euro (1999-2009) and T is a time trend; together with their interaction with inputs and outputs these variables capture (neutral and non neutral) technical change and changes in technology.

E denotes a set of bank-specific and country-specific controls. The bank-specific variables are included to capture differences in size (proxied by fixed assets), risk (measured by the capital-to-assets ratio) and diversification (measured as: $1-\left|\frac{net\ loans - other\ earning\ assets}{total\ earning\ assets}\right|$.[8] Country-specific variables control for differences in macroeconomic activity (measured by GDP per capita) and the structure of respective bank systems (proxied by the ratio of private credit granted by deposit money banks and other financial institutions-to-GDP). Finally, a dummy variable is included to capture the effects of the recent financial crisis from 2007 onwards.

<Insert Table 1 around here>

Following the procedure outlined in Kumbhakar and Lovell (2000) we define and calculate the Divisia index of TFP change for each of the k countries as:

---

influence of OBS on cost and profit efficiency is mixed and the inclusion of non-traditional outputs does not seem to alter the directional impact of environmental variables on bank inefficiency (Lozano-Vivas and Pasiouras, 2010).

[8] This index is defined as in Leaven and Levine (2007). As total earning assets is the sum of net loans and other earning assets, the asset diversification index takes values between zero and one with higher values indicating greater diversification. In this context, a diversified bank is a bank engaging in a diverse set of lending and fee/income-generating activities.

$$\dot{TFP}^{k} = [1-\varepsilon(Y,W,R,T,E;\beta)]\dot{Y}^{c} - \dot{C}(Y,W,R,T,E;\beta) + -\frac{\partial \ln C}{\partial E} + \\ + \sum_{j=1}^{J}[S_j - S_j(Y,W,R,T,E;\beta)]\dot{w}j - \frac{\partial U}{\partial t} \quad (2)$$

In Equation (2) the Divisia index is computed as the sum of five components. The first component measures changes in the optimal scale of operation (SC^k). The second component captures technological progress, measured as shifts of the frontier due to the passing of time (TC^k). The third component measures the impact on TFP of the environmental variables (EX^k). The fourth term measures changes in allocative inefficiency, specified as deviations of the observed inputs cost shares from their optimal ones ($ALLC^k$). The fifth component measures the change in cost efficiency (EC^k) (Denny et al., 1981; Kumbhakar and Lozano-Vivas, 2005).[9] A positive net value in each of the aforementioned components translates into a positive growth in TFP. Equation (2) is first computed for each country using the country-specific parameter estimates derived from Equation (1), and then for the whole industry on the basis of the estimates of the metafrontier.

3.2. The estimation of metafrontiers

If the technology of production differs significantly across countries their data should not be pooled and their efficiency frontiers should be estimated separately; this however precludes meaningful comparisons between them. More formally if there are *k* different technology sets in an input perspective, at every time *t* there will be *k* different input sets each defined as:

[9] Data limitations prevented us from including a potentially sixth component, known as the mark-up effect.

$$L_t^k = \left\{X_t^k : (Y_t^k, X_t^k) \text{ is feasible}\right\} \tag{3}$$

The rationale underlying the metafrontier is that all L^k_t sets belong to a common unrestricted technology set L^*_t $L_t^* = \{L_t^1 \cup L_t^2 \cup L_t^3 \cup .... \cup L_t^k\}$ to which each of the *k* countries has potential access. In other words, the metafrontier allows for the existence of technological spillovers between banks, which was exactly one of the fundamental aims of the eurozone.

The metafrontier is defined as the boundary of this unrestricted technology set and it is derived as the envelope of the single-country frontiers which identifies the metatechnology. In SFA this is estimated by linear or quadratic programming as an overarching function that envelops the single country frontiers. If we define:

$$C_{it}^k = f(X_{it}\beta^k)\exp(v_{it}^k + u_{it}^k) = \exp(X_{it}\beta^k)\exp(v_{it}^k + u_{it}^k) \tag{4}$$

as the *k*-th country cost frontier, that depends on the whole matrix of independent variables X and a vector of country-specific parameters β^k. The metafrontier can be defined as the envelope of the *k* estimations of Equation (4) as:

$$C_{it}^* = f(X_{it}\beta^*) = \exp(X_{it}\beta^*) \tag{5}$$

The functional form of Equation (5) is thus the same as that of Equation (4), with a vector of parameters β^* that has to be derived subject to the constraint that:

$$X_{it}\beta^* \leq X_{it}\beta^k \tag{6}$$

That is, the meta cost technology gives the minimum possible cost available among all the groups.

We estimate Equation (5) by linear programming, hence solving:

$$\text{Min L}=\sum_{i=1}^{N}\sum_{t=1}^{T}(X_{it}\,\beta^{k}-X_{it}\beta^{*}) \tag{7}$$

subject to Equation (6). The radial distance of each bank from the metafrontier is called *metaefficiency* and it is defined as:

$$EFF_{it}^{*}=\frac{\exp(X_{it}\beta^{*}+v_{it}^{k})}{EFF_{it}^{k}} \tag{8}$$

which implies that Equation (4) becomes:

$$EFF_{it}^{*}=\exp(-u_{it}^{k})\frac{\exp(X_{it}\beta^{*})}{\exp(X_{it}\beta^{k})} \tag{9}$$

From Equation (9) we can see that the metaefficiency measure of each bank *i* of country *k* at time *t* is made of two parts: country-specific cost efficiency ($EFF_{it}^{k}=\exp(-u_{it}^{k})$, with $0\leq EFF_{it}^{k}\leq 1$) and a technological gap ratio (TGR). The TGR measures the distance between the metafrontier and the country specific frontier, and it is smaller or equal to unity with higher values indicating a closer proximity to the metafrontier and lower values indicating a larger gap between the two. Empirically then we first estimate EFF^{k} and EFF* and compute the TGR subsequently as their ratio. TGR values across countries and time indicate differences in technological levels. Consequently, TGR values can be used to analyse the technology leaders of the industry.

3.3 The analysis of convergence

The final part of the empirical analysis assesses whether the banking systems in our sample are converging toward the same efficiency and technology. In order to ensure that our analysis is robust, we adopt two approaches. First, we calculate the speed with which countries are catching up with the best technology available by means of a catch-up (CU) index (Chen and Yang, 2011). This is defined as the ratio of the technical change of the metafrontier to that of the national frontier for each bank *i* at time *t* (i.e. between t and t-1) as:

$$CU_{it} = \frac{TC_{it}^{*}}{TC_{it}^{k}} \tag{10}$$

When comparing across banks or tracking individual banks over time, the catch-up index provides an indication of the difference in the speed of convergence towards the metafrontier. Lower (higher) values of CU indicate a faster (slower) speed of convergence. Convergence of the CU index towards the metafrontier is formally tested via an ADF unit root test. We also perform a long-run test for the existence of β and σ convergence in the levels of cost efficiency and metaefficiency before and after the introduction of the euro as follows:

$$\ln P2_i - \ln P1_i = \gamma_0 + \lambda \ln P1_i + \gamma_r X_{ri} + \varepsilon_i \tag{11}$$

where $P1_i = \sum_{t=1}^{s} \frac{P_{it}}{s}$ and $P2_i = \sum_{s+1}^{T} \frac{P_{it}}{(T-s-1)}$ are the average efficiency (and then metaefficiency) levels of country *i* before and after the euro respectively, and *X*s are country-specific variables (in our study country dummies) to allow for conditional convergence. Absolute β-convergence is found if λ <0 and γ_r = 0, and conditional β convergence is found if λ <0 and γ_r is ≠ 0; β convergence is thus defined as a significant negative correlation between the level of efficiency and its growth rate. If this negative correlation is really due to convergence and not simply to a process of mean-reversion, σ-convergence must also be present, that is a significant reduction in the dispersion levels of efficiency between countries over time. The detection of σ-convergence is based on a test suggested by Lichtenberg (1994) which is defined as:

$$c = \frac{R^2}{(1+\lambda)^2} \sim F^{NT-k}_{NT-k} \tag{12}$$

where k is the number of explanatory variables in Equation (11) and the null hypothesis is the presence of σ-convergence. Equations (11) and (12) are estimated with respect to both cost efficiency (that is the distance of a bank from its own country frontier) and metaefficiency (the distance of a bank from the metafrontier, which is defined by the product of cost efficiency and TGR). The results will shed light on if and how the banking industries in our sample are moving towards the best available technology and increasing common levels of efficiency.

4. Data

Our dataset provides a unique opportunity to examine the evolution of bank efficiency and productivity change during the last two decades. This period encompassed many structural and regulatory changes in EU banking (as discussed in Section 1). Data are collected from banks' annual balance sheet and income statements made available via the Bankscope database over the period 1992 to 2009. This dataset presents a number of challenges, particularly in terms of creating consistent time series, as the definition of some of the variables of interest changed with the adoption of International Financial Reporting Standards (IFRS). Most banks in the sample stopped reporting their accounts using Generally Accepted Accounting Principles (GAAP) over the sample period. From January 1st, 2005, all EU listed banks were required to implement IFRS and most large unlisted banks also switched to IFRS.

In an effort to ensure consistency, our sample considers only commercial banks operating in the countries initially forming the monetary union (EU-12). Data were revised for reporting errors, inconsistencies and missing values. Following Kashyap and Stein (2000) and Cetorelli and Goldberg (2011), we apply a number of filters to our sample. We exclude banks with missing data on relevant accounting variables, including assets, loans, other earning assets, deposits, equity, interest income and non-interest income. To ensure that the results are not driven by outliers, we restrict our analysis to commercial banks with a loan to assets ratio greater than 10%. Further, we eliminate those banks that operate mainly as credit specialists, or which provide asset management and private banking services as their main activity. We also eliminate foreign branches if the bank does not have retail operations in a specific country. If banks underwent M&A during the sample period they were treated as separate units until the M&A, except in the calculation of the Divisia indices where their values were summed for the year before the M&A to make the calculation possible. Because of the limited number of observations remaining after applying these filters, we excluded Finland, Ireland and Luxembourg. The final sample covers commercial banks operating in nine of the original EU-12 countries (Austria, Belgium, France, Germany, Greece, Italy, Netherlands, Spain, and Portugal) for the period 1992 to 2009, thus providing a maximum of 18 time-series observations on each bank. All data were converted into euro prior to 1999 and deflated using the domestic GDP deflator with 2005 as a base year. Table 2 provides balance sheet details for all banks in our sample; data is shown for three reference dates (1992, 1999 and 2009) providing snapshots at the beginning of the sample period, at the introduction of the euro and at the end of the sample period.

< Insert Table 2 around here>

Table 2 indicates that the median bank size has grown substantially over time. This is undoubtedly a consequence of the process of consolidation which has taken place over that period (Goddard et al., 2007, 2010). The increase in bank size is particularly marked in Belgium and in the Mediterranean countries (Spain, Portugal, Italy and Greece). The median value for fixed assets has remained fairly constant (or even decreased) in some countries over time. Banks in all sample countries record similar equity-to-assets ratios, with Italian and Dutch banks relatively better capitalised compared to their EU peers.

Differences across countries become more apparent when considering the extent to which banks engage in traditional lending versus fee and trading-based activities. This is measured by the loans-to-total assets ratio. While the loan-to-asset ratio has been increasing in all EU-9 countries over the sample period (especially since 2000), the Italian, French, Spanish and Portuguese banks appear to specialise predominantly in lending activities. This is also reflected in lower levels of asset diversification index (defined as $1-\left|\frac{net\ loans - other\ earning\ assets}{total\ earning\ assets}\right|$). Interestingly, the asset diversification index displays an overall decrease over time, thus reinforcing the finding that asset growth in eurozone banking has been driven mainly by an increase in lending activities. Although these patterns of bank growth have been heterogeneous across the EU-9, we investigate whether lending decisions of banks are determined by bank-level productivity.

5. Empirical results

This section presents the results of our empirical analysis of bank productivity in the eurozone. The section comprises five parts. Section 5.1 discusses the results from estimating country-specific frontiers and their TFP changes and components. This is justified on the grounds that the hypothesis of a common frontier that pools all the countries together is strongly rejected by the data.[10] In Section 5.2, we present the results from the estimation of the metafrontier and its Divisia index. Section 5.3 discusses the decomposition of overall performance into cost efficiency and technology gaps. We augment this analysis in Section 5.4 via the construction of a catch-up index to deepen the understanding of technological leadership. Finally, in Section 5.5, the results of the convergence tests are presented and discussed.

5.1 Country- specific analysis of efficiency, Total Factor Productivity and its decomposition

The first part of the analysis consists of estimating Equations (1) and (2) at the country level, such that the efficiency scores reflect the distance to different (national) benchmarks. Equation (1) is estimated by Maximum Likelihood (ML), with linear homogeneity in input prices and Young's symmetry imposed prior to estimation. The results show that the cost function is always consistent with its theoretical properties, inputs and

[10] This is performed as an LR test for parameters stability. The null is rejected even when allowing for different country intercepts in the unrestricted model.

outputs point elasticities have the expected sign and inefficiency is always significant.[11] Furthermore, the euro dummies are negative and significant for the majority of countries. This suggests that the introduction of the single currency matters in either reducing banks' total costs or in changing their technology of production, or both. Finally, the dummy variable that controls for the effects of the recent financial crisis (when significant) is positive as expected, thus indicating that the crisis either increased bank costs, forced banks to change their production technology, or both.

Turning to efficiency levels, the results indicate a general decline in performance over 1999 to 2009, compared to the previous decade (with an overall average decline of 1.4% reported for the nine eurozone banking systems). A deterioration in efficiency over time can often be the result of technological improvements, as these shift the frontier upwards making it therefore more difficult for banks to reach it. Such a process can be revealed by the results of the estimation of the Divisia index. These are summarised in Table 3.

Table 3 shows the results of the TFP index and its components for the entire sample period from 1992 to 2009, and for the two sub-periods, 1992 to 1998 and 1999 to 2009. We also present separately the results for the 2007 to 2009 period, in order to isolate any possible effects of the financial crisis on the observed results for the 1999 to 2009 period. Indeed in this sub-period the vast majority of countries experienced either no changes or a deterioration in efficiency levels.

<Insert Table 3 around here>

[11] To conserve space, our results are not reported in full. However, these are available from the authors upon request.

The results show (without exception) that all countries in our sample experienced increases in the TFP index over 1992 to 2009. Increases in TFP are particularly pronounced in Austria (4%) and Italy (1.2%). Growth in TFP has been brought about mainly by technical change (TC) for all countries (with the exception of Austria, where improvements in allocative efficiency dominate). Among the most plausible reasons for these positive shifts in the production frontiers is the extent of technological advances and automation that transformed the processing and analysis of financial data, as well as delivery systems used to distribute financial products and services to bank customers. The importance of the scale component is nevertheless negligible while the changes in efficiency tend to mirror those in technology.

5.2. Metafrontier analysis of Total Factor Productivity

To allow for meaningful cross country comparisons, this section discusses the findings derived from the estimation of a metafrontier. Along with a first single metafrontier covering the entire sample period, we construct two separate metafrontiers for all nine countries, pre- (1992 to 1998) and post- (1999 to 2009) the introduction of the euro. There are two main reasons for splitting the sample. First, the relatively long 18-year time span of our sample period was characterised by dramatic technology advances in the European banking industry. Second, the significance of the Euro dummies may indicate a possible structural break in the data series. Our model specification allows therefore a more flexible modelling of the time on technology, and for more meaningful comparisons of the TFP index and efficiency scores across countries. This is particularly relevant in the context of the creation of a single market in the EU.

As discussed in Section 3.2, the metafrontiers are derived by estimating Equation (7) subject to Equation (6) by linear programming. To conserve space, we do not report the full set of estimated coefficients. However, two points are of particular interest. First, the results are consistent with the theoretical properties of a cost function. Second they indicate a reduction in the optimal scale of production of loans, with a corresponding reduction in the optimal share of interest expenditure among the inputs. This implies that banks which chose to produce loans beyond the minimum efficient scale experience dis-economies of scale.

This ideal pattern is followed more or less closely by all countries with the exception of the Netherlands, whose technological changes go in the opposite direction. In the rest of this section we focus on the Divisia TFP index results, while the metaefficiency scores are examined in Section 5.3 together with the analysis of the technological gap ratios (TGR).

Table 4 provides estimates of the TFP metafrontier changes by country along with its five components. With only two exceptions (Greece and Spain), we find clear evidence of TFP growth over the sample period. This is primarily driven by technological change that is invariably greater than 1 (with peaks ranging between 1.5% and 2% per year). While this positive change in technology takes place both before and after the introduction of the euro for all the countries, not all of them experience continuous increase in TFP after 1999. Specifically, Austria, France, Italy, Portugal and the Netherlands experience a sustained improvement in technology. The remaining countries experience no such sustained increase due to allocative or technical efficiencies.

To summarise, overall the metafrontier is shifting outwards and some of the countries appear to be lagging behind, as the analysis of TGR will clarify. Finally, Austrian, Italian and Portuguese banks show resilience to the 2007 crisis, evidenced by productivity indices greater than 1 during the 2007 to 2009 period.

<Insert Table 4 around here>

5.3. Meta efficiency and Technology Gap Ratios

As explained in Section 3.2 above (see Equation 9), the metaefficiency score of a bank is its distance from the metafrontier. It can be decomposed into cost efficiency (the distance from the country frontier) and technology gap ratio (TGR). TGRs are measured by the distance between the country and metafrontier. The resultant values range from zero to one, with higher values indicating a closer proximity to the metafrontier.[12] The TGRs and the efficiency scores are reported in Table 5.

<Insert Table 5 around here>

With the notable exception of Italy, all countries show higher TGRs in the first period. The average EU-9 gap between the metafrontier and its national counterparts widened from 0.878 to 0.815 over the two sub-periods. This confirms that technical improvements are shifting the metafrontier upwards with some countries contributing to the best available technology more than others that therefore lag behind. The lowest TGR is found in the Netherlands in the second period (which could be due to the non optimal change in technology discussed before). Furthermore, being relatively small and highly concentrated, the Dutch banking sector was subjected to a period of turmoil when several of its largest

[12] For example a TGR value of 0.8 for bank *i* would mean that even if bank *i* were operating on the national best practice frontier (i.e. it is fully efficient), it could potentially cut its frontier costs by 20 per cent if it adopted the best EU-9 metatechnology. On the other hand, a TGR value of 1 indicates that the bank is using the best technology although not necessarily in the most efficient way.

banks received government support to alleviate financial distress in the wake of the 2007 financial crisis. Italian banks instead score better with consistently high TGR both before and after the introduction of the euro, thus contributing to the metafrontier more than others (i.e. their banks are using the best technology available). It is not unusual for Italian banks to score well in terms of relative productivity levels (Casu et al., 2004). Recent evidence (comparing the parametric Divisia TFP index of Italian and German banks) finds that the rates of change are over 2.5 times bigger for Italy than Germany over the period 1994-2004 (Fiorentino et al., 2008).

Table 6 reports the ‘technology leaders’ in our sample. These are banks that have a TGR equal to 1 (and so are supposedly using the best technology available, although not necessarily in the most efficiency way). The results confirm the leading position of Italian banks especially after the introduction of the euro. Until 1998, France has the highest number of technology leaders, closely followed by Italy and Germany. After 1999 Italian banks present the largest share of the “technology leaders”. Only Belgium and Greece have no technology leaders in either sub-period. Banks in these countries exhibit comparatively lower loan-to-asset-ratios and higher diversification (particularly in the early years of the analysis).

<Insert Table 6 around here>

5.4. Speed of Convergence in Technical Change

The results of the empirical analysis thus far imply that technology improved significantly over time with some countries overtaking others. In this and the following section we investigate the speed and level of technical and efficiency change. Specifically, Section 5.4 computes a catch-up index in order to assess the speed of convergence toward the metafrontier. Section 5.5 tests for the convergence of country-specific frontiers toward the metafrontier by means of an Augmented Dickey Fuller (ADF) unit root test. This is supported by tests of β and σ convergence. The results of these tests are particularly relevant for regulatory agencies tasked with monitoring integration in the European banking industry.

The first part of our dynamic analysis looks at the so-called catch-up index (CU_{it}) (Chen and Yang, 2011); this is defined as the ratio of the technical change of the metafrontier to that of the national frontier for each bank *i* at time *t* (i.e. between t and t-1) as defined in equation (10). The catch-up index provides an indication of the difference in the speed of convergence towards the metafrontier. Lower (higher) values of the CU index indicate a faster (slower) speed of convergence.

Table 7 reports the average results per country in three separate time periods: 1992-1998, 1999-2006 and 2007-2009. The results reveal that, with the exception of Austria, Germany (and to a lesser extent Portugal), all countries experience a decline in the catch-up index over the sub-periods 1992 to 1998 (column a) and 1999 to 2006 (column b). This corresponds to an increase in the speed of convergence after the introduction of the euro in 1999 for the majority of countries in our sample. The trend, however, changes as a result of the 2007 financial crisis (column c), after which, for all countries without exception, the speed of convergence slows down considerably.[13] Table 7 also shows that the Netherlands, Spain and Italy are on average the countries that move the fastest towards the metafrontier, while Germany, Austria and Belgium are the slowest.

<Insert Table 7 around here>

5.5. Unit root test and β and σ convergence

[13] This corresponds to recent evidence that suggests that integration of the EU banking industry has declined since the onset of the financial crisis (ECB, 2011).

To check the robustness of the above interpretation, we test explicitly for the convergence of country-specific frontiers towards the metafrontier by means of an Augmented Dickey Fuller (ADF) unit root test (Thirtle, 2003). Namely if:

$$\ln TC_t^k = \gamma_k + \lambda \ln\left(\frac{TC^*_{t-1}}{TC_{t-1}^k}\right) + \ln TC_{t-1}^k + \varepsilon_t \tag{13}$$

and

$$\ln TC^*_t = \gamma^* + \ln TC^*_{t-1} + \eta_t \tag{14}$$

combining (13) and (14) we get:

$$\ln\left(\frac{TC_t^k}{TC^*_t}\right) = (\gamma_k - \gamma^*) + (1-\lambda)\ln\left(\frac{TC_{t-1}^k}{TC^*_{t-1}}\right) + \phi_t \tag{15}$$

Equation (15) is estimated for all the EU-9 countries and the ADF test is performed on it. Specifically the presence of a unit root (λ=0) means that there are no technical spillovers between the metafrontier and the national frontier, therefore no catching up towards the best technology and no convergence to it. Convergence is found instead if λ>0 (so no unit root is found) with full convergence given by (γ^k-γ*) = 0, that is a non significant intercept in (15). The results of this test are reported in Table 8. We find evidence of convergence towards the metafrontier for all countries with the exception of Austria, Germany and Portugal. These results therefore confirm the findings of the analysis of the catch-up index carried out in the previous section

<Insert Table 8 around here>

We augment the ADF test to check for β and σ-convergence (explained in Section 3.3 above). Absolute β-convergence is found if (in Equation 10) λ <0 and $\gamma_r = 0$. Conditional β convergence is found if λ <0 and $\gamma \neq 0$; this is a necessary but not sufficient condition and to be able to conclude for the presence of convergence one has to find σ-convergence as well, which is tested for by the statistic *c*. [14] The results presented in Table 9, show the existence of absolute β and σ convergence. This implies that all the countries in the sample are moving progressively closer to full efficiency. In the case of metaefficiency, convergence is not found (conditional or otherwise) for the whole sample of EU-9 countries (as indicated by the insignificant *c* statistic in the row labelled metaefficiency 1). Conditional convergence is found if we remove the Netherlands, Austria and Germany from the sample (see row metaefficiency 2 in Table 9), with country dummies jointly although not individually significant. Given that metaefficiency is the product of TGR and cost efficiency, and that the latter is converging in all the countries of the sample, we are led to conclude that the difference in metaefficiency convergence scores is due to differences in TGR. In other words (and similar to the results presented above), banks in most countries sampled have taken advantage of the technical improvements have taken place in European banking since the introduction of the euro.

< Insert Table 9 around here>

[14] We use country specific dummies as additional variables for the case of conditional convergence. These are not reported in the table as they are not relevant *per se* to the conclusions.

6. Conclusions

This study investigates productivity growth and convergence in technical change and efficiency for a sample of European commercial banks operating in nine eurozone countries over the period 1992-2009. During the period of our investigation regulatory reforms aimed at fostering integration and changes in the operating environment have occurred. Our empirical investigation involves the estimation of a parametric metafrontier TFP Divisia index which enables us to account for technology heterogeneity, and identify technology gaps across countries. In order to assess whether countries are moving towards the best available technology and efficiency, two separate tests of convergence are carried out.

The results from estimating country-specific frontiers (the pooled frontier was rejected by the data) show that commercial banks operating in the nine eurozone countries experienced productivity growth over the period 1992 to 2009. Evidence presented suggests that banks' operations were affected significantly by the introduction of the single currency in 1999 (that contributed to either reducing banks' costs or in changing their technology of production or, indeed, both); and the recent financial crisis (which for many banking systems) produced the reverse. The analysis of the components underlying TFP change shows that the growth in productivity has occurred due to improvements in technology. This finding reflects the benefits of computerisation and automation that transformed the processing and analysis of financial data, as well as delivery systems used to deliver financial products and services to bank customers.

Evidence derived from the estimation of a eurozone metafrontier and the computation of the Divisia index largely confirms the results from the single-country frontiers. The change in technology that takes place both before and after the introduction of the euro is positive for all the countries in the sample. This analysis also allows us to identify that in only five out of nine countries (Austria, France, Italy, Portugal and the Netherlands) a continuous increase in

TFP after 1999 occurred. Similarly, while some banking systems appear to have suffered significantly as a result of the 2007 crisis, others (Austria, Italy and Portugal) have shown some resilience. In terms of best practice, banks headquartered in the largest banking sectors, i.e. France, Germany and (particularly after 1999), Italy, appear to dominate the metafrontier, thus implying that banks from these eurozone countries have been using the best technology available. At the other end of the spectrum, Belgian and Greek banks never make it to the best practice metafrontier during the period under investigation.

The analysis of convergence carried out by means of the catch-up index and the unit root test shows two main patterns in the technical change convergence process. First, there is convergence of technical change towards the metafrontier for most countries in our sample. Second, the speed of efficiency convergence has accelerated after the introduction of the single currency before decreasing in all nine eurozone countries after the 2007 crisis. In a similar vein, our tests for β and σ-convergence provide evidence that all countries are moving progressively closer to full efficiency. The results for metaefficiency, instead, suggest convergence only when Austria, Germany and the Netherlands are excluded from the sample. Given that metaefficiency is the product of TGR and cost efficiency, and that the latter is converging in all the countries of the sample, we are led to conclude that while technical improvements have certainly taken place in eurozone banking systems since the introduction of the euro, most but not all countries have taken full advantage of them.

Overall this investigation has shown that the efforts toward the creation of a single market did contribute to significant productivity gains for the banking sectors in the eurozone countries. Our analysis suggests that technological progress is the most important driver of productivity change. However, not all banking systems appear to have benefited in a similar way from deregulation. Rather, environmental changes (brought about by policies aimed at increasing competition and fostering integration) have impacted differently on banks' costs and technology of production. Whereas some countries have taken full advantage from the changes, others are still lagging behind. While our investigation provides clear evidence of convergence in technical change and cost efficiency, a metaefficiency convergence has not yet been achieved. There appears little doubt that technical improvements have occurred in European banking since 1999, but not all banking systems have taken full advantage of these.

We conclude by contending that policy actions at the EU level, including the introduction of the euro appear to have increased TFP. However, there is a danger that the improvements in the productivity and integration of financial markets might be damaged if policy measures to deal banking stability prioritize stability over productivity growth.

References

Aigner, D., Lovell, C.A.K., Schmidt, P., 1977. Formulation and estimation of stochastic frontier production models. Journal of Econometrics 6, 21–37.

Alam, I.M.S., 2001. A non-parametric approach for assessing productivity dynamics of large banks. Journal of Money, Credit and Banking 33, 121–139.

Altunbas, Y., Goddard, J., Molyneux, P., 1999. Technical change in banking. Economics Letters 64, 215–221.

Avkiran, N.K., 2000. Rising productivity of Australian trading banks under deregulation 1986-1995. Journal of Economics and Finance 24, 122–140.

Bartelsman, E., Haskel, J.E., Martin, R., 2008. Distance to which frontier? Evidence of productivity convergence from international firm-level data. Centre for Economic Policy Research Paper 7032.

Battese, G.E., Heshmati, A., Hjalmarsson, L., 2000. Efficiency of labour use in the Swedish banking industry: A stochastic frontier approach. Empirical Economics 25, 623–640.

Battese, G.E., Rao, D.S.P., O' Donnell, C.J., 2004. A metafrontier production function for estimation of technical efficiencies and technology gaps for firms operating under different technologies. Journal of Productivity Analysis 21, 91–103.

Bauer, P.W., Berger, A.N., Humphrey, D.B., 1993. Efficiency and productivity growth in US banking. In Fried, H.O., Knox Lovell, C.A., Schmidt, S.S. (Eds.) The Measurement of productive efficiency: Techniques and applications, Oxford University Press, New York.

Berger A.N., Humphrey, D.D., 1997. Efficiency of financial institutions: International survey and directions for future research. European Journal of Operational Research 98, 282–94.

Berger, A.N., Mester, L.J., 2003. Explaining the dramatic changes in performance of US banks: Technological change, deregulation, and dynamic changes in competition. Journal of Financial Intermediation 12, 57–95.

Berger, A.N., 2007. International comparisons of banking efficiency. Financial Markets, Institutions and Instruments 16, 119–14.

Bos, J.W.B., Schmiedel, H., 2007. Is there a single frontier in a single European banking market? Journal of Banking & Finance 31, 2081–2102.

Canhoto, A., Dermine, J., 2003 A note on banking efficiency in Portugal, new vs. old banks. Journal of Banking & Finance 27, 2087–2098.

Casu, B., Girardone, C., 2010. Integration and Efficiency Convergence in EU Banking Markets. Omega, The International Journal of Management Science 38, 260–267.

Casu, B., Girardone, C., Molyneux, P., 2004. Productivity change in European banking: A comparison of parametric and non-parametric approaches. Journal of Banking & Finance 28, 2521–2540.

Cetorelli, N., Goldberg, L.S., 2011. Banking Globalization and Monetary Transmission. Journal of Finance (forthcoming).

Chen, K.H., Yang, H.Y., 2011. A cross-country comparison of productivity growth using a generalized metafrontier Malmquist productivity index: With application to banking industries in Taiwan and China. Journal of Productivity Analysis 35, 197–212.

Delis, M.D., Molyneux, P., Pasiouras, F., 2011. Regulations and productivity growth in banking: Evidence from transition economies. Journal of Money, Credit and Banking 43, 735–764.

Denny, M., Fuss, M., Waverman, L., 1981. The measurement and interpretation of total factor productivity in regulated industries, with an application to Canadian telecommunications. In: Cowing, T.G., Stevenson, R.E. (Eds.), Productivity Measurement in Regulated Industries. Academic Press, New York.

ECB., 2011. Financial Integration in Europe. European Central Bank, Frankfurt.

Fiorentino E., De Vincenzo A., Heid, F., Karmann A., Koetter M., 2010. The effects of privatization and consolidation on bank productivity: Comparative evidence from Italy and Germany. Deutsche Bundesbank, Discussion Paper Series 2: Banking and Financial Studies Number 03/2009.

Fried, H.O., Lovell, C.A.K., Schmidt, S. S., 2008. The Measurement of Productive Efficiency and Productivity Change. Oxford University Press, Oxford.

Gilbert, R.A. Wilson, P.W., 1998. Effect of deregulation on the productivity of Korean banks. Journal of Economics and Business 50, 133–155.

Goddard, J.A., Molyneux, P., Wilson, J.O.S., Tavakoli, M., 2007. European banking: An overview. Journal of Banking & Finance 31, 1911–35.

Goddard, J., Molyneux, P., Wilson, J.O.S., 2010. Banking in the European Union In: Berger, A.N., Molyneux, P., Wilson, J.O.S. (eds.) Oxford Handbook of Banking. Oxford, Oxford University Press.

Grifell-Tatjé, E., Lovell, C.A.K., 1996. Deregulation and productivity decline: The case of Spanish savings banks. European Economic Review 40, 1281–1303.

Grifell-Tatjé, E., Lovell, C.A.K., 1997. The sources of productivity change in Spanish banking. European Journal of Operational Research 98, 364–380.

Gropp, R., Kashyap, A., 2009. A New Metric for Banking Integration in Europe. National Bureau of Economic Research Working Paper Number 14735.

Hughes, J. P., Mester, L.J., 2010. Efficiency in banking: Theory, practice and evidence. In: Berger A.N., Molyneux, P., Wilson, J.O.S. (Eds.) Oxford Handbook of Banking. Oxford University Press, Oxford.

Humphrey, D.B., 1992. Flow versus stock indicators of banking output: Effects on productivity and scale economy measurement. Journal of Financial Services Research 6, 115–135.

Isik, I., Hassan, M.K., 2003. Financial deregulation and total factor productivity change: An empirical study of Turkish commercial banks. Journal of Banking & Finance 27, 1455–1485.

Kashyap, A.K., Stein, J.C., 2000. What Do a Million Observations on Banks Say about the Transmission of Monetary Policy? The American Economic Review 90, 3, 407–428.

Koetter, M., Poghosyan, T., 2009. The identification of technology regimes in banking: Implications for the market power-fragility nexus. Journal of Banking & Finance 33, 1413–1422.

Kontolaimou, A., Tsekouras, K., 2010. Are cooperatives the weakest link in European banking? A non-parametric metafrontier approach. Journal of Banking & Finance 34, 1946–1957.

Kumbhakar, S.C., Lozano-Vivas, A., Lovell, C.A.K., Hasan, I., 2001. The effect of deregulation on the performance of financial institutions: The case of Spanish saving banks. Journal of Money, Credit and Banking 33,101–119.

Kumbhakar, S.C., Lovell, C.A.K., 2000. Stochastic Frontier Analysis. Cambridge University Press, New York.

Kumbhakar, S.C., Sarkar, S., 2003. Deregulation, ownership and productivity growth in the banking industry: Evidence from India. Journal of Money, Credit and Banking 35, 403–414.

Kumbhakar, S.C., Lozano-Vivas, A., 2005. Deregulation and productivity: The case of Spanish banks. Journal of Regulatory Economics 27, 331–351.

Laeven, L., Levine, R., 2007. Is There a Diversification Discount in Financial Conglomerates? Journal of Financial Economics 85, 331–67.

Leightner, J.E., Lovell, C.A.K., 1998. The impact of financial liberalization on the performance of Thai banks. Journal of Economics and Business 50, 115–131.

Lichtenberg, F.R., 1994. Testing the convergence hypothesis, Review of Economics and Statistics 76, 576–579.

Lozano-Vivas, A., 1998. Efficiency and technical change for Spanish banks. Applied Financial Economics 8, 289–300.

Lozano-Vivas, A., Pasiouras, F., 2010. The impact of non-traditional activities on the estimation of bank efficiency: International evidence. Journal of Banking & Finance 34, 1436–1449.

Malmquist, S., 1953. Index numbers and indifference surfaces. Trabajos de Estatistica 4, 209–242.

Meeusen W., Van den Broek, J., 1977. Efficiency estimations from Cobb-Douglas production functions with composed error. International Economic Review 18, 435–444.

Mendes, V., Rebelo, J., 1999. Productive efficiency, technological change and productivity in Portuguese banking. Applied Financial Economics 9, 513–521.

Mukherjee, K., Ray, S.C., Miller, S.M., 2001. Productivity growth in large US commercial banks: The initial post-deregulation experience. Journal of Banking & Finance 25, 913–939.

O'Donnell, C.J., Rao, D.S.P., Battese, G.E., 2008. Metafrontier frameworks for the study of firm-level efficiencies and technology ratios. Empirical Economics 34, 231–255.

Sealey, G. W., Lindley, J. T., 1977. Inputs, outputs and a theory of production and cost at depository financial institutions. Journal of Finance 32, 1251–1266.

Stiroh, K. J., 2000. How did Bank Holding Companies Prosper in the 1990s? Journal of Banking & Finance 24, 1703–1745.

Sturm, J.E., Williams, B., 2004. Foreign bank entry, deregulation and bank efficiency: Lessons from the Australian experience. Journal of Banking & Finance 28, 1775–1799.

Syverson, C., 2011. What determines productivity? Journal of Economic Literature 49, 326–365.

Tirtiroglu, D., Daniels, K.N., Tirtiroglu, E., 2005. Deregulation, intensity of competition, industry evolution and the productivity growth of US commercial banks. Journal of Money, Credit and Banking 37, 339–360.

Wheelock, D.C., Wilson, P.W., 1999. Technical Progress, Inefficiency, and Productivity Change in US Banking, 1984-93. Journal of Money, Credit, and Banking 31, 212–234.

Table 1

Descriptive statistics (1992-2009)

Variable	*Mean*	*Median*	*St.dev.*
Total operating costs (TC)	1382712	102204.3	4581316
Loans (y_1)	12907514	903661.1	46279579
Other Earning Assets (y_2)	11811574	532677.2	50247428
Cost of labour (w_1)	0.0474	0.0410	0.0312
Loanable funds price (w_2)	0.0163	0.0150	0.0096
Cost of capital and other admin costs (w_3)	0.0121	0.0107	0.0080
Fixed assets	229938	20729	803405
Equity/Total assets	0.0752	0.0627	0.0558
Diversification Index	0.6363	0.6744	0.2472
Private Credit of Financial Institutions-to-GDP	0.89	0.86	0.26

Note: All data are deflated using 2005 as the base year.

Table 2

Aggregate Balance Sheet information for commercial banks in nine eurozone countries[a]

	Austria	*Belgium*	*France*	*Germany*	*Greece*	*Italy*	*Netherlands*	*Portugal*	*Spain*	*Eurozone 9*
Total n. of bank obs. (1992 - 2009)	304	286	1275	851	243	1159	256	185	639	5198
Asset size (median value)										
- 1992	1926114	2339389	897738	763790	3267180	2232901	1980017	5220053	2390250	1740288
- 1999	928578	2456136	1011732	507134	5490137	1296134	2572592	8039684	2804964	1384887
- 2009	1541589	8602475	1820635	676070	24531446	3437677	3413934	10438946	14066080	2907317
Loans (median value)										
- 1992	1182591	1182500	508607	418060	1011071	967653	998998	1550775	1280567	824925
- 1999	655234	875776	473736	324737	2291144	793629	1240915	4259284	1975854	750638
- 2009	686958	6200753	1452738	354378	18429990	2511313	1794479	8700204	12121491	2018421
Other Earning Assets (median value)										
- 1992	616995	1471433	306767	413547	1724992	824173	921538	2874742	879186	659543
- 1999	300282	1431997	341081	206477	2590326	502042	1150269	3048613	846076	508052
- 2009	470125	2133867	358356	258997	6566238	514292	1349406	1114585	2327270	718883
Fixed Assets (median value)										
- 1992	41637	27928	10049	8775	78814	59723	8652	136460	53191	27239
- 1999	25919	32280	9723	8482	68592	23056	13776	93997	64593	17211
- 2009	13341	30630	16535	6233	210218	29343	45553	55946	122552	23833
Equity/Assets (median value)										
- 1992	0.053973	0.033049	0.040242	0.054540	0.067273	0.077697	0.049592	0.074066	0.080467	0.061274
- 1999	0.047050	0.050098	0.053796	0.051471	0.136969	0.081876	0.067735	0.062980	0.065372	0.062608
- 2009	0.072728	0.053399	0.063028	0.059371	0.058266	0.083036	0.080203	0.060310	0.063961	0.067514
Loans/Assets (median value)										
- 1992	0.587775	0.342204	0.549992	0.560740	0.312195	0.466232	0.504540	0.392364	0.511482	0.486348
- 1999	0.628947	0.381950	0.536249	0.551771	0.431789	0.557890	0.521224	0.469950	0.611990	0.546037
- 2009	0.577988	0.457119	0.736430	0.553126	0.690825	0.733072	0.524197	0.786926	0.705516	0.663584
Diversification Index (median value)										
- 1992	0.694335	0.711200	0.645025	0.698442	0.712582	0.863022	0.713675	0.878249	0.825848	0.777237
- 1999	0.571736	0.692040	0.615081	0.629866	0.908675	0.722682	0.788473	0.773341	0.684503	0.685323
- 2009	0.630515	0.815539	0.442994	0.631176	0.507269	0.457453	0.732358	0.282313	0.505543	0.533371

[a] Values are in euro mil. All data are deflated using 2005 as the base year.

Table 3

Single country frontiers: Divisia TFP change and its components [a]

Countries	*Years*	*TFP*	*SC*	*TC*	*EX*	*ALLC*	*EC*
Austria	1992-1998	1.072	1.001	1.008	1.000	1.062	1.001
	1999-2006	1.016	1.004	0.995	1.000	1.019	0.999
	2007-2009	1.104	0.999	0.987	1.001	1.119	0.998
	1999-2009	1.013	1.003	0.993	1.000	1.019	0.999
	1992-2009	**1.040**	**1.002**	**0.999**	**1.001**	**1.039**	**1.000**
Belgium	1992-1998	1.002	1.000	1.005	0.996	1.001	1.000
	1999-2006	1.000	1.000	1.003	0.994	1.003	1.000
	2007-2009	1.007	0.998	1.001	1.017	0.991	1.000
	1999-2009	1.002	1.000	1.002	0.999	1.001	1.000
	1992-2009	**1.004**	**1.000**	**1.003**	**1.000**	**1.001**	**1.000**
France	1992-1998	0.999	1.000	1.005	0.997	0.998	0.999
	1999-2006	1.005	1.001	1.011	0.992	1.003	0.998
	2007-2009	1.015	1.000	1.016	1.003	0.995	1.000
	1999-2009	1.007	1.001	1.013	0.993	1.002	0.999
	1992-2009	**1.007**	**1.001**	**1.010**	**0.998**	**1.000**	**0.999**
Germany	1992-1998	1.005	1.001	1.025	0.984	0.995	0.999
	1999-2006	0.999	1.001	0.999	1.001	1.002	0.995
	2007-2009	0.995	1.000	0.981	1.020	1.000	0.994
	1999-2009	0.996	1.001	0.994	1.005	1.001	0.995
	1992-2009	**1.001**	**1.001**	**1.006**	**0.998**	**0.999**	**0.997**
Greece	1992-1998	1.004	1.001	1.004	1.000	1.000	1.000
	1999-2006	1.013	1.001	1.013	0.993	1.002	1.004
	2007-2009	1.002	1.002	1.024	0.989	0.996	0.990
	1999-2009	1.015	1.002	1.016	0.992	1.002	1.002
	1992-2009	**1.009**	**1.001**	**1.011**	**0.995**	**1.001**	**1.000**
Italy	1992-1998	1.019	1.000	1.032	0.992	0.995	1.000
	1999-2006	1.007	1.000	1.028	0.974	1.007	0.999
	2007-2009	1.005	0.999	1.030	0.995	0.977	1.000
	1999-2009	1.011	1.000	1.028	0.977	1.005	1.000
	1992-2009	**1.012**	**1.000**	**1.030**	**0.983**	**1.000**	**1.000**
Netherlands	1992-1998	1.001	1.002	1.021	0.980	0.997	1.001
	1999-2006	1.002	1.005	1.034	0.964	0.997	1.002
	2007-2009	0.976	0.998	1.045	0.937	1.009	0.985
	1999-2009	0.997	1.004	1.037	0.958	0.998	0.999
	1992-2009	**1.002**	**1.003**	**1.031**	**0.971**	**0.997**	**0.999**
Portugal	1992-1998	1.012	1.001	1.033	0.973	1.002	1.003
	1999-2006	1.004	1.001	1.023	0.987	0.989	1.003
	2007-2009	1.014	1.002	1.016	0.996	0.992	1.006
	1999-2009	1.007	1.001	1.021	0.988	0.992	1.003
	1992-2009	**1.008**	**1.001**	**1.026**	**0.979**	**0.997**	**1.004**
Spain	1992-1998	0.996	1.001	1.010	0.992	0.998	0.996
	1999-2006	1.012	1.003	1.023	1.003	1.002	0.982
	2007-2009	1.018	1.001	1.039	1.035	0.983	0.959
	1999-2009	1.021	1.003	1.027	1.011	1.001	0.979
	1992-2009	**1.009**	**1.002**	**1.020**	**1.001**	**1.000**	**0.987**

[a] The Divisia index is decomposed into scale (SC); technical change (TC), environmental (EX), allocative efficiency (ALLC), and cost efficiency (EC).

Table 4
Metafrontier Divisia Index: Divisia TFP change and its components [a]

Countries	*Years*	*TFP*	*SC*	*TC*	*EX*	*ALLC*	*EC*
Austria	1992-1998	1.083	1.000	1.017	1.001	1.064	1.001
	1999-2006	1.033	0.996	1.004	1.000	1.034	0.999
	2007-2009	1.092	1.001	1.017	1.003	1.074	0.998
	1999-2009	1.031	0.997	1.007	1.000	1.028	0.999
	1992-2009	**1.054**	**0.999**	**1.011**	**1.003**	**1.042**	**1.000**
Belgium	1992-1998	1.010	0.999	1.024	0.996	0.991	1.000
	1999-2006	0.998	0.999	1.007	0.994	0.998	1.000
	2007-2009	0.955	1.006	1.023	1.017	0.908	1.000
	1999-2009	0.998	1.001	1.011	0.999	0.986	1.000
	1992-2009	**1.005**	**1.000**	**1.016**	**1.000**	**0.989**	**1.000**
France	1992-1998	1.016	1.000	1.020	1.004	0.993	0.999
	1999-2006	1.002	1.000	1.003	1.000	1.000	0.998
	2007-2009	0.989	1.000	1.018	1.005	0.965	1.000
	1999-2009	1.004	1.000	1.007	1.001	0.997	0.999
	1992-2009	**1.011**	**1.000**	**1.012**	**1.004**	**0.996**	**0.999**
Germany	1992-1998	1.007	1.000	1.019	0.998	0.990	0.999
	1999-2006	0.998	0.999	1.005	0.999	0.999	0.995
	2007-2009	0.964	1.000	1.017	1.000	0.953	0.994
	1999-2009	0.996	0.999	1.008	0.999	0.994	0.995
	1992-2009	**1.000**	**1.000**	**1.012**	**1.000**	**0.992**	**0.997**
Greece	1992-1998	1.011	1.000	1.018	1.001	0.992	1.000
	1999-2006	0.980	0.999	1.006	0.989	0.981	1.004
	2007-2009	0.991	1.000	1.022	1.004	0.974	0.990
	1999-2009	0.993	0.999	1.010	0.993	0.987	1.002
	1992-2009	**0.997**	**0.999**	**1.013**	**0.995**	**0.990**	**1.000**
Italy	1992-1998	1.023	0.999	1.024	1.003	0.997	1.000
	1999-2006	1.004	0.999	1.003	0.996	1.007	0.999
	2007-2009	1.006	0.999	1.020	1.004	0.980	1.000
	1999-2009	1.011	0.999	1.008	0.998	1.005	1.000
	1992-2009	**1.015**	**0.999**	**1.014**	**1.001**	**1.001**	**1.000**
Netherlands	1992-1998	1.014	0.998	1.021	1.001	0.993	1.001
	1999-2006	1.021	0.994	1.009	0.999	1.017	1.002
	2007-2009	0.937	1.001	1.022	1.010	0.917	0.985
	1999-2009	1.010	0.995	1.012	1.002	1.001	0.999
	1992-2009	**1.011**	**0.996**	**1.015**	**1.003**	**0.997**	**0.999**
Portugal	1992-1998	1.010	0.999	1.026	0.998	0.984	1.003
	1999-2006	0.991	1.000	1.013	1.002	0.972	1.003
	2007-2009	1.020	0.999	1.024	1.008	0.975	1.006
	1999-2009	1.010	0.999	1.016	1.003	0.985	1.003
	1992-2009	**1.007**	**0.999**	**1.020**	**0.998**	**0.985**	**1.004**
Spain	1992-1998	1.006	1.000	1.021	1.001	0.989	0.996
	1999-2006	0.998	0.998	1.000	1.000	1.017	0.982
	2007-2009	0.952	1.000	1.023	1.014	0.952	0.959
	1999-2009	0.991	0.998	1.007	1.003	1.002	0.979
	1992-2009	**0.994**	**0.999**	**1.012**	**0.998**	**0.997**	**0.986**

[a] The Divisia index is decomposed into scale (SC); technical change (TC), environmental (EX), allocative efficiency (ALLC), and cost efficiency (EC).

Table 5

TGR, cost efficiency and metaefficiency

	TGR	*Cost efficiency*	*Metaefficiency*
Austria			
1992-1998	0.902	0.967	0.872
1999-2009	0.761	0.969	0.737
1992-2009	**0.775**	**0.968**	**0.751**
Belgium			
1992-1998	0.790	1.000	0.79
1999-2009	0.702	1.000	0.702
1992-2009	**0.730**	**1.000**	**0.730**
France			
1992-1998	0.865	0.963	0.833
1999-2009	0.790	0.963	0.762
1992-2009	**0.774**	**0.963**	**0.769**
Germany			
1992-1998	0.887	0.94	0.833
1999-2009	0.803	0.929	0.747
1992-2009	**0.796**	**0.934**	**0.744**
Greece			
1992-1998	0.866	0.953	0.826
1999-2009	0.782	0.956	0.748
1992-2009	**0.797**	**0.955**	**0.775**
Italy			
1992-1998	0.927	0.955	0.885
1999-2009	0.940	0.946	0.890
1992-2009	**0.811**	**0.95**	**0.896**
Netherlands			
1992-1998	0.795	0.967	0.769
1999-2009	0.611	0.957	0.584
1992-2009	**0.944**	**0.961**	**0.606**
Portugal			
1992-1998	0.902	0.953	0.86
1999-2009	0.729	0.956	0.697
1992-2009	**0.630**	**0.954**	**0.718**
Spain			
1992-1998	0.874	0.978	0.855
1999-2009	0.837	0.901	0.753
1992-2009	**0.776**	**0.942**	**0.728**

Table 6

Technology leaders by country [a]

	1992-1998		*1999-2009*		*1992-2009*	
	No.	%	No.	%	No.	%
Austria	3	0.12	2	0.09	4	0.13
Belgium	0	0.00	0	0.00	0	0.00
France	6	0.24	1	0.05	5	0.06
Germany	5	0.20	5	0.23	2	0.16
Greece	1	0.04	0	0.00	0	0.00
Italy	5	0.20	14	0.64	18	0.56
Netherlands	2	0.08	0	0.00	0	0.00
Portugal	3	0.12	0	0.00	0	0.00
Spain	0	0.00	0	0.00	3	0.09
Eurozone 9	**25**	**1.00**	**22**	**1.00**	**32**	**1.00**

[a] The table shows the number of banks who have a TGR=1 for each country. The % figure is the share of technology leaders in each country.

Table 7

Catch-up indices of technological change[a]

	1992-1998 (a)	1999-2006 (b)	Change (a) to (b)	2007- 2009 (c)	Change (b) to (c)	1999-2009 (d)	Change (a) to (d)	1992-1999 (e)
Austria	1.008	1.008	=	1.029	↑	1.015	↑	1.012
Belgium	1.019	1.005	↓	1.020	↑	1.009	↓	1.013
France	1.012	0.993	↓	1.001	↑	0.995	↓	1.001
Germany	0.995	1.005	↑	1.033	↑	1.014	↑	1.007
Greece	1.014	0.994	↓	0.997	↑	0.994	↓	1.002
Italy	0.992	0.976	↓	0.989	↑	0.980	↓	0.984
Netherlands	0.999	0.976	↓	0.977	↑	0.976	↓	0.985
Portugal	0.993	0.990	↓	1.006	↑	0.995	↑	0.994
Spain	1.011	0.981	↓	0.985	↑	0.980	↓	0.992

[a] A positive (negative) increase over time implies a lower (greater) speed of catch-up.

Table 8

ADF Unit root test of convergence [a]

	Lambda λ	p-values	Constant term $\gamma_k-\gamma^*$	p-values
Austria	0.107	0.251	-0.002	0.304
Belgium	0.342	0.042	-0.004	0.104
France	0.365	0.043	0.0004	0.814
Germany	0.390	0.658	0.007	0.138
Greece	0.235	0.038	0.0003	0.83
Italy	0.327	0.02	0.005	0.07
Netherlands	0.159	0.057	0.003	0.104
Portugal	0.209	0.179	0.0005	0.815
Spain	0.243	0.067	0.003	0.256

[a] The equation is estimated from the ADF test with one lagged difference term. We report directly the value of λ. The ADF statistics is the t-ratio for -λ and its McKinnon p-value is reported here.

Table 9

Tests for β- and σ-convergence

	Coefficients	*p-values*
Cost efficiency: Eff (k)		
λ	-0.786	0.041
c	6.144[a]	0.001
Metaefficiency 1: Eff(*)		
λ	-0.514	0.001
c	0.312[a]	0.999
Metaefficiency 2: Eff (*)		
λ	-0.475	0.001
c	1.37[a]	0.05

[a] *c* statistics (F-distribution).