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Integration, Productivity and Technological Spillovers: Evidence for Eurozone Banking Industries

By *Barbara Casu, Alessandra Ferrari, Claudia Girardone and John O.S. Wilson*

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Integration, productivity and technological spillovers: Evidence for Eurozone banking industries

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ABSTRACT

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JEL Codes G21; D24.

Keywords: European Banking; Financial Integration, Convergence, Productivity Growth.

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Integration, productivity and technological spillovers:

Evidence for Eurozone banking industries

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ABSTRACT

In the context of the debate on increased integration of Eurozone banking markets, this paper evaluates the impact of the Single Market on bank productivity and assesses the cross-border benefits of integration in terms of technological spillovers. We utilise a parametric meta-frontier Divisia index to estimate productivity change and identify technological gaps. We then assess the extent to which productivity converges within and across banking industries as a result of technological spillovers. Our results suggest that bank productivity growth has occurred for most Eurozone countries up to the onset of the financial crisis, but has since reversed. Technological spillovers do exist, and have led to progression toward the best technology. However, convergence is not complete and significant long run differences in productivity persist. Improvements in technology are increasingly driven by a smaller number of banks and concentrated in fewer banking industries.

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1. Introduction

The notion that financial integration brings multiple benefits and ultimately leads to economic growth has been prevalent amongst policymakers in the European Union.[1] This view informed the path towards the Single Market for Financial Services and has been the subject of renewed scrutiny following the financial crisis of 2007 and subsequent Eurozone crisis of 2010, which resulted in calls for a closer union between banks in the Eurozone.

This study contributes to the debate on the perceived benefits of increased integration by examining the growth in bank productivity since the onset of the EU single market project (the signing of the Maastricht Treaty in 1992) as well as cross-border benefits in terms of technological spillovers. Evaluation of bank productivity growth and convergence is an essential component to the current debate on further Eurozone integration. The potential benefits from any move toward increased financial integration should be informed by an empirical evaluation of whether banks in all Eurozone member states benefit equally from access to technology and any resultant technological spillovers.

Previous attempts to assess bank total factor productivity (TFP) growth in European banking have produced rather mixed results. Earlier studies find that technical change systematically reduced European banks' total costs during the 1990s (Altunbas et al., 1999; Battese et al. 2000). Casu et al. (2004) estimate productivity change in European banking during the 1990s to find that only banks in some countries benefited from productivity growth. These conflicting results are often unexplained by the existing bank efficiency literature.[2]

[1] Financial integration is thought to bring a number of benefits, which ultimately lead to enhanced economic growth via increased capital accumulation and improvements in productivity (Pagano, 1993; Giannetti et al., 2002; Bonfiglioli, 2008). Benefits of financial integration arise from increased financial development via the entry of foreign banks, which bring an influx of new capital, product and process innovations, which spur the development of domestic banks. This in turn can lead to an increase in the supply of investment funds, and a reduction in the cost of capital (Jappelli and Pagano, 2008). Financial integration also improves capital allocation, by fostering a reallocation of investments toward more productive projects and more efficient risk-sharing, stemming from the efficient diversification of country-specific shocks (Baele et al., 2004; Jappelli and Pagano 2008; Kalemli-Ozcan and Manganelli, 2008).

[2] Hughes and Mester (2014) provide a comprehensive review of the literature.

Related literature explores the extent of banking integration via tests of convergence in efficiency and profitability of European banks. These studies find some evidence of convergence, but long run differences in profitability and efficiency (Gropp and Kashyap, 2009; Casu and Girardone, 2010; Goddard et al, 2013).

In this study we utilise a bank-level data set to estimate a parametric Eurozone-level meta-frontier based on stochastic country-specific efficiency frontiers (Battese et al., 2004; O'Donnell et al., 2008). This allows us to calculate a Divisia index of total factor productivity (TFP) change and its components (Casu et al. 2013).[3] The meta-frontier accounts for any technological heterogeneity, and identifies gaps in technology across countries (Bos and Schmiedel, 2007; Kontolaimou and Tsekouras, 2010). We test whether the creation of a single market for financial services fostered bank productivity growth, and if so, whether this varies across Eurozone banking industries. The underlying mechanisms driving productivity growth are also investigated. We then explore whether there are differences across Eurozone countries which prevent some banking industries from taking full advantage of the best available technology. If this is the case, some banking industries will diverge from the productivity growth rate of the Eurozone meta-frontier. As a consequence, further integration is not obtainable.

The extent to which productivity converges within and across banking industries in the Eurozone as a result of technological spillovers is also investigated. In order to do so, we construct a catch-up index, and execute a variety of convergence tests (which exploit both the time series and cross sectional dimensions of the data set) to explore the efficiency, meta-efficiency and technical gap ratios of the banking industries in our sample.

The period of our study (which spans 1992 to 2009) provides a unique opportunity to examine the evolution of bank productivity during a time which encompasses significant

[3] Total factor productivity (TFP) growth measures productivity improvements generated from technical progress and changes in efficiency. This is a commonly used indicator in assessing the role of technology in determining input productivity.

regulatory reform and the most intense phase of the banking crisis in the Eurozone. The results derived from estimating country-specific frontiers suggest that banks experience productivity growth over the sample period. The introduction of the single currency in 1999 appears to have enhanced productivity, while the on-going financial crisis appears to have resulted in the reverse. Our analysis of the constituent components underlying TFP change shows that the growth in productivity occurs due to improvements in technology, which allows banks to deliver financial products and services more efficiently. The estimation of the Eurozone meta-frontier and the derived Divisia indices confirm these results. Changes in technology before and after the introduction of the single currency have a positive impact on productivity, although this slows over time, and reverses after the onset of the financial crisis.

The results of the convergence analysis suggest that technological spillovers (which transfer the best technology across borders) between banking industries within the Eurozone exist. However, these spillovers are not complete and persistent differences in productivity remain across banking industries. Evidence suggests that improvements in technology are increasingly driven by a smaller number of banks and concentrated in fewer banking industries. Hence, regulatory change and advances in technology appear to have favoured a small number of banks and led to increased differences between banks within the Eurozone.

Overall the results presented in this paper suggest that policy actions at the EU level, (including the introduction of the single currency) appear to have increased TFP. However, while there is some evidence of convergence in bank productivity, this is limited.

The remainder of this paper is structured as follows. Section 2 presents the dataset. Section 3 describes the methodology and the results of the country specific analysis of efficiency and TFP growth. The results of the meta-frontier and the cross-country TFP growth analyses are reported in Section 4. Section 5 presents an analysis of convergence, while Section 6 concludes.

2. Data

The data used in this study is collected from banks' annual balance sheet and income statements made available via the Bankscope database over the period 1992 to 2009.[4] In order to ensure consistency, our sample considers commercial banks operating in countries that initially formed a monetary union (EU-12). Data is revised for reporting errors, inconsistencies and missing values. Following Kashyap and Stein (2000) and Cetorelli and Goldberg (2012), 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%. Furthermore, we eliminate those banks that operate as credit specialists, or which provide asset management and private banking services as their main activity. Banks involved in M&A during the sample period are treated as separate units prior to the M&A, except in the calculation of the Divisia indices where values are summed for the year before the M&A to make the calculation possible. Due to the limited number of observations remaining after applying these filters, we exclude banks located in 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 1 presents the median value of the main variables for all banks in our sample at: the beginning of the sample period (1992); at the introduction of the single currency (1999); and at the end of the sample period (2009).

[4] 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 changes with the adoption of International Financial Reporting Standards (IFRS). Most banks in the sample ceased reporting using Generally Accepted Accounting Principles (GAAP) during the sample period. From January 1st, 2005, all EU listed banks were required to implement IFRS. Most large unlisted banks also switched to IFRS

< Insert Table 1 near here>

As Table 1 shows, median bank size has grown substantially over time. This is undoubtedly a consequence of the process of consolidation which has taken place over the sample period (Goddard et al., 2007, 2010). The increase in bank size is particularly marked in Spain, Belgium and Greece. Banks in all sample countries record similar equity-to-assets ratios, with Italian banks relatively better capitalised compared to the rest.

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 banking industries 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 diversification, which display 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.

3. Country-specific efficiency, Total Factor Productivity and its decomposition

In this section, we discuss the methodology and present the results of the empirical analysis of country-specific efficiency and Total Factor Productivity change. This is necessary given that the hypothesis of a common frontier that pools all the countries together is strongly rejected by the data.[5] The resultant analysis provides an overview of the main characteristics and changes for each banking industry in the sample. It is the first necessary

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

step towards the estimation of the meta-frontier-based cross country analysis performed in Section 4.

The stochastic cost frontier comprises a cost function with a composite error term made up of two separate, but jointly estimated, components of noise v_{it} ~N(0, σ^2) and inefficiency u_{it} (Aigner et al., 1977; Meeusen and Van den Broek, 1977). The performance of banks is evaluated in terms of their radial distance from the frontier, which arises solely from noise if they are perfectly efficient, and has a positive inefficiency component otherwise. There are several possible theoretical distributions for the inefficiency component of the cost function. This study uses a parametric Likelihood Ratio (LR) test to choose between nested models. The non-parametric Akaike criterion is used when models are non-nested.[6]

The flexible translog functional form for our model is as follows:

$$\begin{aligned}\ln C_{it} &= \alpha_0 + \sum_{m=1}^{2}\alpha_m \ln y_{mit} + \sum_{j=1}^{3}\beta_j \ln w_{jit} + \sum_{m=1}^{2}\sum_{q=1}^{2}\alpha_{mq} \ln y_{mit} \ln y_{qit} + \\ &+ \sum_{n=1}^{3}\sum_{j=1}^{3}\beta_{nj} \ln w_{nit} \ln w_{jit} + \sum_{j=1}^{3}\sum_{m=1}^{2}\gamma_{jm} \ln w_{jit} \ln y_{mit} + \\ &+ \lambda_1 T + \lambda_2 T^2 + \sum_{m=1}^{2}\theta_m T \ln y_{mit} + \sum_{j=1}^{3}\zeta_j T \ln w_{jit} + eEUR + \sum_{m=1}^{2} e_m EUR \ln y_{mit} + \\ &+ \sum_{j=1}^{3} e_j EUR \ln w_{jit} + \sum_{p}^{P}\eta_p E_{it} + \eta_c D07_t + v_{it} + u_{it}\end{aligned} \qquad (1)$$

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)

[6] The most general distribution is a truncated normal with variable mean, which nests the truncated normal with constant mean, which nests the half normal. The alternative to these is the exponential, and that requires the use of the Akaike criterion. Kumbhakar and Lovell (2000) provide a detailed exposition of the frontier model.

and other earning assets (y_2).[7] EUR is a dummy variable set equal to 1 for the period following the introduction of the single currency (1999-2009), and *T* is a time trend. Both these aforementioned variables are interacted with inputs and outputs to capture neutral and non-neutral technical change and technological progress.

E denotes a set of bank-specific and country-specific controls. The bank-specific variables are included to capture differences in size (fixed assets proxy the banks' branch network), risk (measured by the capital-to-assets ratio), and diversification, measured as:

$$1-\left|\frac{net\ loans - other\ earning\ assets}{total\ earning\ assets}\right|$$

Country-specific variables control for differences in macroeconomic activity (measured by GDP per capita), and for the structure of respective banking industries (proxied by the ratio of private credit granted by deposit money banks and other financial institutions-to-GDP). Finally, the dummy variable *D07* captures the effects of the recent financial crisis from 2007 onwards.

Following Kumbhakar and Lovell (2000), the Divisia index of TFP change for each of the *k* countries is given by:

$$\dot{TFP} = \left[1-\varepsilon(y,w,T,E;\beta)\right]\dot{Y}^{c} - \dot{C}(y,w,T,E;\beta) - \frac{\partial \ln C}{\partial E} + \sum_{j=1}^{J}\left[S_j - S_j(y,w,T,E;\beta)\right]\dot{w}_j - \frac{\partial u}{\partial T} \qquad (2)$$

[7] The output variable "other earning assets" is a summary variable which includes most non-lending activities that generate fee and commission income (including: Loans and Advances to Banks; Reverse repos and cash collateral; Trading securities; Derivatives; Available for sale securities; Held to maturity securities; Other securities; Investments in property; Insurance assets and Other earning assets). The variable does not include other OBS items (in the form of, for example, off-balance sheet exposure to securitisations, committed credit lines and other contingent liabilities). Given our long sample period and the need to build consistent time series of the relevant variables, we had to make a choice in term of inclusion/exclusion of particular OBS activities as a separate 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, the lack of the relevant data in the earlier years of the sample (particularly between 1992 and the mid-2000s) as well as the substantial cross-county differences lead us to exclude securitisation activities.

Where: $$\dot{Y}^c = \sum_{m=1}^{M} \left[\frac{\varepsilon_m(y, w, T; \beta}{\varepsilon(y, w, T; \beta} \right] \dot{y}_m$$

In Equation (2), the Divisia index comprises five components. The first measures changes in the optimal scale of operation (*SC*). The second captures technological progress, measured as shifts of the frontier over time (*TC*). The third measures the impact of the environmental variables (*EX*). The fourth measures changes in allocative inefficiency, specified as a difference between the observed and the optimal inputs cost shares (*ALLC*). Finally, the fifth component measures changes in cost efficiency (*EC*). A positive value in each of these components translates into a positive growth in TFP.[8] 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 meta-frontier.

We model Equation (1) as a translog where inefficiency u_{it} is i.i.d. and independent of the error v_{it} and the regressors. The preferred distribution for inefficiency in the current study is the exponential, with additional heterogeneity entering in the form of heteroskedasticity. The model is estimated by Maximum Likelihood (ML), with linear homogeneity in input prices and Young's symmetry imposed prior to estimation. The results indicate that the cost function is always consistent with its theoretical properties. A summary of the main results is presented in Table 2.[9] Inputs and outputs point elasticities have expected sign. Inefficiency is always statistically significant (except for Belgium). Increases in diversification appear to significantly reduce costs (as do, in most cases) increases in the equity to assets ratio. Increases in the levels of fixed assets (as expected) increase costs. The euro dummies are

[8] When reporting our results we transform the growth rate values of the Divisia index (which are positive or negative) into growth values which are larger or smaller than one.

[9] To conserve space, since they are not at the core of the paper these results are not reported in full. However, these results are available from the authors upon request.

jointly significant for all countries implying that the introduction of the single currency led to a reduction in banks' total costs (negative intercept dummy) or a change in production technology (significant interaction dummies), or both. The only notable exceptions are Greece (and to a lesser extent the Netherlands), as the test of joint significance is rejected with p-values respectively of 0.78 and 0.12. Finally, the dummy variable D07 is in most cases positive and significant, implying that the financial crisis led to an increase bank costs.

<Insert Table 2 near here>

Turning to efficiency levels, the results indicate a mild decrease in performance after the introduction of the single currency. Changes in efficiency over time can often be the result of technological improvements. Such improvements shift the frontier making it more difficult for banks to reach it. This is illustrated by the results of the estimation of the Divisia index, which are presented in Table 3. Table 3 also presents 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. In order to illustrate any possible effects of the financial crisis, we also present separately the results for the 2007 to 2009 period. The superscript *k* is used to distinguish these results from those based on the meta-frontier estimated in Section 4.

<Insert Table 3 near here>

The results indicate that, with the exception of the Netherlands, all banking industries in our sample experience increases in TFP^k between 1992 and 2009. These yearly changes range from 0% in the Netherlands to 2.4% in Portugal. The improvements accelerate after the introduction of the common currency and slow down or become negative after the onset of the financial crisis. Technical change (TC^k) contributes positively to this growth in all but two countries (Austria and Belgium) across the whole time period. 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 during the sample period, as well as delivery systems used to distribute financial products and services to bank customers (Goddard et al., 2010). Changes in scale efficiency (SC^k) are also positive across the sample, while the changes in cost efficiency (EC^k) are generally small.[10]

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4. Total Factor Productivity and technology gaps: a meta-frontier analysis

The estimation of meta-frontiers is a useful way to address the problem of technological heterogeneity across the *k* countries. The rationale underlying the meta-frontier is that the *k* different technologies belong to a common meta-technology set to which each banking industry has potential access (Battese et al. 2004). In other words, the meta-frontier allows for the possibility of technological spillovers between banks.

The meta-frontier is defined as the boundary of this meta-technology set and is estimated as the envelope of the single-country (estimated previously) stochastic frontiers. If the country-specific frontiers are given by:

$$C_{it}^{k} = f(X_{it}\beta^{k})\exp(v_{it}^{k} + u_{it}^{k}) = \exp(X_{it}\beta^{k})\exp(v_{it}^{k} + u_{it}^{k}) \qquad (3)$$

with country specific parameters β^k, the meta-frontier can be written as

$$C_{it}^{*} = f(X_{it}\beta^{*}) = \exp(X_{it}\beta^{*}) \qquad (4)$$

[10] This is expected since technological improvements will shift the frontier upwards and thus make it more difficult for banks to attain it.

Equation (4) envelopes the k estimations of Equation (3) using the same functional form to derive a set of parameters $\beta*$ such that the meta-technology has the minimum possible cost, i.e.:

$$X_{it}\beta* \leq X_{it}\beta^k \tag{5}$$

The meta-frontier is estimated by linear programming, hence solving:

$$Min\ L = \sum_{i=1}^{N}\sum_{t=1}^{T}(X_{it}\,\beta^k - X_{it}\beta*) \tag{6}$$

subject to Equation (5). Given the deterministic nature of this approach, we bootstrap the results to test the significance of the estimated coefficients. Once the meta-frontier is estimated, the distance of each bank from it defines its *meta-efficiency* score (EFF*). This comprises two parts: the banking industry country-specific efficiency and the technological gap ratio (TGR):

$$EFF_{it}^{*} = \exp(-u_{it}^{k})\frac{\exp(X_{it}\beta*)}{\exp(X_{it}\beta^{k})} \tag{7}$$

The TGR measures the distance between the country frontier and the meta-frontier. Values range from zero to one. Higher values indicate a closer proximity to the meta-frontier (i.e. to the best possible technology, and vice versa).[11] TGR values are used to identify the technology leaders of a given banking industry. Differences between countries imply the existence of technology gaps.

[11] For example a TGR value of 0.8 for bank *i* implies that even if bank *i* were operating on the national best practice frontier (i.e. it is fully efficient), it could potentially cut its costs by 20 per cent if it adopted the best meta-technology. 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 manner.

As in the case of the single countries analysis above, we next use these estimates to compute Divisia indices of total factor productivity. The results are reported in Table 4, which shows the estimates by country of the TFP meta-frontier index (TFP*) along with its five components.[12] The TGRs and the efficiency scores are reported in Table 5.

We find clear evidence of TFP* growth over the whole sample period for all banking industries. This growth is sustained and continues after the introduction of the common currency albeit at a slower pace before ceasing with the onset of the financial crisis where it becomes negative. The improvement in TFP* is driven primarily by technological change (TC*) which is invariably greater than one (values range between 1.1% and 1.7% per year) for all countries both before and after the introduction of the single currency, although it slows down somewhat as time progresses. Cost efficiency (EC*) and especially scale efficiency (SC*) do not appear to change very much this time whereas allocative efficiency (ALLC*) gets progressively worse and is one of the main reasons for the reduction in TFP*. Overall, the results suggest that the meta-technology is improving over time causing adjustments in the efficiency with which banks in different countries perform their activity. The analysis of the TGR and convergence (in Section 6) clarifies how banking industries in Eurozone countries compare in this respect.

<Insert Table 4 around here>

<Insert Table 5 around here>

Table 5 reports average TGR values across all banks in each country before and after the introduction of the single currency, as well as overall. All banking industries show a

[12] The superscript * is used now to indicate results from the meta-frontier as opposed to those from the single countries.

reduction in TGR values following the introduction of the common currency, implying that on average banks are slipping further away from the best available technology. This suggests that the technical improvements implied by the value of the Divisia index for both before *and* after 1999 (albeit at a slower pace) must be led by a small number of banks, or by some banking industries. These "technology leaders" are contributing to the best available technology while other banks lag behind. On average the lowest TGR is found in the Dutch banking industry, which was subjected to a period of turmoil when several of its largest banks received government support to alleviate financial distress in the wake of the 2007 financial crisis. Italian banks appear to score much better than banks in other countries, with TGRs higher than 0.9, both before and after the introduction of the single currency. As a consequence Italian banks contribute to the meta-frontier (using the best technology available) more than others. It is not unusual for Italian banks to score well in terms of relative productivity levels (Casu et al., 2004).[13]

Table 6 examines the technology leaders in the sample (which we define as the banks in the 95th percentile, with a TGR value $\geq$ 0.95).[14] The number of technology leaders decrease from 248 before 1999 (approximately 10% of the sample) to 152 after the introduction of the single currency (about 5% of the sample). This is consistent with our intuition that improvements do take place, but are increasingly driven by a smaller number of banks, and are more concentrated with fewer banking industries.

Before 1999, the contributions to the meta-frontier are more evenly distributed across all banking industries, even though the Italian banking industry stands out as the best performer. After the adoption of the single currency, the Italian banking industry leads the changes with a staggering 70% of technology leaders, followed by the 20% of Germany, the

[13] Recent evidence comparing the TFP growth of Italian and German banks finds that the rates of change are over 2.5 times larger for Italy than Germany over the period 1994-2004 (Fiorentino et al., 2009).

[14] Given the deterministic nature of the meta-frontier a higher threshold would have reduced the number of relevant observations too much to offer any useful insight.

remaining 10% being divided across the other banking industries in our sample. These findings are consistent with recent literature suggesting that recent advances in technology and changes in regulation have favoured a small number of banks (Wheelock and Wilson, 2012). As a consequence it appears that the regulatory effort towards integration may have led to increased differences between banks within the Eurozone, particularly since 1999.

<Insert Table 6 around here>

5. Technical change, efficiency change and convergence

In this section we assess whether the banking industries in the sample converge toward the same efficiency and technology. There are several approaches in the literature to the measurement of convergence. These fall into two main categories: cross sectional and time series approaches.[15] The first approach we use is based on the time series properties of the data and examines whether there is a catch up process of banking industries toward the meta-frontier. We calculate a catch-up (*CU*) index to measure the speed at which banking industries catch up to the best technology (Chen and Yang, 2011); and then test for convergence towards this best technology by means of panel unit root tests. This is augmented with a second approach by testing specifically for the existence of β and σ-convergence in the measures of performance.

5.1 Catch-up index and panel unit root tests

The CU index is defined as the ratio of the technical change of the meta-frontier to that of the country frontier; averaging across banks for each country k at time t (i.e. between t and $t-1$). This is defined as:

[15] For a comprehensive discussion of the relative merits of these two approaches to the measurement of convergence see Bernard and Durlauf (1996) and Islam (2003).

$$CU_{kt} = \frac{TC_{kt}^{*}}{TC_{kt}} \tag{8}$$

The catch-up index provides an indication of the difference in the speed of convergence towards the meta-frontier between banking industries and over time. Lower values of *CU* indicate a faster speed of convergence, and vice versa. The existence of a process of convergence towards the meta-frontier can be formally tested with unit root tests, such as the Dickey Fuller (D-F). Especially if performed at the individual country level the D-F test has low power, a problem that can be partly obviated by using panel unit root tests. This is therefore the approach we decide to follow.

If the data generating process is given by:

$$\ln TC_{kt} = \gamma^{k} + \lambda \ln\left(\frac{TC^{*}_{k,t-1}}{TC_{k,t-1}}\right) + \ln TC_{k,t-1} + \varepsilon_{kt} \tag{9}$$

and

$$\ln TC^{*}_{kt} = \gamma^{*} + \ln TC^{*}_{k,t-1} + \eta_{kt} \tag{10}$$

Then combining (9) and (10) we get:

$$\ln\left(\frac{TC_{kt}}{TC^{*}_{kt}}\right) = \gamma + (1-\lambda)\ln\left(\frac{TC_{k,t-1}}{TC^{*}_{k,t-1}}\right) + \phi_{kt} \tag{11}$$

where $\gamma = (\gamma^{k}-\gamma^{*})$. The presence of a unit root in (11) would be indicative of no technical spillovers between the meta-frontier and the national frontiers. Therefore no catching up and no convergence toward the best technology. Convergence is found instead if $\lambda > 0$. Equation

(11) can be specified to accommodate for additional regressors, such as lagged terms of the dependent variable, country-specific intercepts and/or different convergence parameters.

There are several panel unit root tests available in the literature that vary depending on: the relative size and asymptotic properties of the cross sectional and time dimensions; the null and alternative hypotheses; and the assumptions made about cross sectional differences etc.[16] We choose to perform three different tests, all suitable for the case where T > N.[17] The first is the Levin-Lin-Chu test (2002) that formulates a null hypothesis of no stationarity for the whole panel and a restrictive alternative where all the series share the same autoregressive coefficient. The second is a Fisher-type test following Choi (2001), consisting of a combination of p-values from various unit root tests. The null is non-stationarity, but the alternative allows for different autoregressive coefficients. Finally the Hadri LM test (2000) tests for the hypothesis that all series are (trend) stationary against the alternative that at least some of the panels have a unit root.[18] The results of this part of the analysis are reported in Table 7 and 8.

<Insert Table 7 around here>

Table 7 reports the catch up index of each banking industry in separate time periods: 1992-1998, 1999-2009 further broken into 1999-2006 and 2007-2009. With the exception of Austria, Germany and Greece all countries show a decline in the catch-up index before and after 1999 (column *a* vs column *d*). This indicates an increase in the speed of convergence after the introduction of the single currency, and can be explained by the slowing down of the improvements in meta-technology discussed previously. As we discussed earlier, technical change on the meta-frontier continues to take place but at a slower pace, with fewer banks

[16] Islam (2003) provides a useful survey of convergence tests.
[17] Recall that in this case the panel is defined by 9 countries observed over a period of 14 years.
[18] The unit root equation is formulated differently from (11) in the Hadri test; since the intuition behind the various tests is the same we omit further details.

and fewer countries contributing to the frontier. This trend of a faster speed of convergence is however mostly concentrated before the onset of the financial crisis (as the index values before and after 2007 increase for most countries, see columns *b* and *c*).[19] In terms of cross country banking industry comparisons, Italy stands out as the fastest moving industry again, with the lowest catch-up index both before and after the introduction of the single currency. This is not surprising given the Italian banking industry has the highest average TGR values, and the largest number of banks contributing to the meta-frontier. The slowing down in the German banking industry signals an increase in the difference between the best performing banks (the technology leaders) and their poorer performing counterparts.[20]

Table 8 reports the results of the panel root tests. In all specifications we allow for country fixed effects; when possible we also do not include a time trend, as this would lower the power of the tests (Baltagi 2008). The null hypothesis of non-stationarity is rejected both in the LLC and the Fisher-type tests (more strongly in the latter than in the former) suggesting that a process of convergence towards the meta-frontier could be taking place. Rejection of the null does not necessarily indicate that all the panels are stationary, and this is confirmed by the Hadri test which rejects the hypothesis of stationarity for the whole panel in favour of stationarity for some of the countries only. Overall, these results appear to suggest that a process of convergence is taking place, but is not shared by all the banking industries in the sample, consistently with the simple CU analysis of the previous section.

<Insert Table 8 around here>

[19] 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, 2012).

[20] The distribution of technology leaders in Germany is indeed very small, with always the same, very few banks repeatedly appearing as best performers over time. The distribution in Italy for instance is about twice as large.

We also estimate augmented Dickey Fuller (ADF) tests on Equation (11) for each banking industry in our sample. In this case again the null is that of a unit root indicated by an insignificant λ, with full convergence given by an insignificant intercept. The results are reported in Table 9, and are consistent with the above interpretation.

<Insert Table 9 around here>

5.2 β and σ-convergence

We also examine the cross sectional characteristics of the panel data set at the bank level. Specifically we test for the existence of β and σ-convergence in the levels of cost efficiency, meta-efficiency and TGR, both in the long run (before and after the introduction of the single currency) and in the short run (year-by-year) for the whole panel. Specifically, if P_{kit} is the measure of performance under consideration for bank i at time t in country k the tests for long run (superscript l) and short run (superscript s) convergence are performed respectively as follows (Fung, 2006):

$$\ln P2_{ki} - \ln P1_{ki} = \gamma_0^l + \lambda^l \ln P1_{ki} + \gamma_r^l X_{rki} + \varepsilon_{ki} \qquad (12)$$

$$\ln P_{kit} - \ln P_{ki,t-1} = \gamma_0^s + \lambda^s \ln P_{ki,t-1} + \gamma_r^s X_{rki} + \varepsilon_{kit} \qquad (13)$$

In Equation (12)

$P1_{ki} = \sum_{t=1}^{s} \frac{P_{kit}}{s}$ and $P2_{ki} = \sum_{s+1}^{T} \frac{P_{kit}}{(T-s-1)}$

These are the average efficiency (or meta-efficiency or TGR) levels of bank i in country k before and after the introduction of the single currency respectively, and X is a vector of country dummies to allow for conditional convergence. Significance indicates that countries are moving towards separate steady-state productivity levels. In both equations absolute β-convergence is found if $\lambda < 0$ and $\gamma_r = 0$, and conditional β-convergence is found if $\lambda < 0$ and γ_r is $\neq 0$. β-convergence is thus defined as a significant negative correlation between the level of efficiency and its growth rate. The speed of adjustment is measured by λ with half-life measured as ln(0.5)/ln(1+λ). If this negative correlation is due to convergence and not simply to a process of mean-reversion, then σ-convergence must also be present, that is a significant reduction in the dispersion levels of efficiency between countries over time. Following Lichtenberg (1994) our test statistic for σ-convergence is given by:

$$c = \frac{R^2}{(1+\lambda)^2} \sim F^{N-q}_{N-q} \tag{14}$$

Where: q is the number of explanatory variables in Equations (12) and (13) and the null hypothesis is the presence of σ-convergence.

The results presented in Table 10 indicate the existence of conditional β convergence confirmed by σ convergence, both in the long and the short run, and across all three performance measures (cost efficiency, meta-efficiency and TGR). The results of the short run analysis (that tracks changes on a year-by-year basis) suggests a rapid speed of convergence in cost efficiency (of 39.2% a year, corresponding to a half-life of 1.4 years), which is consistent with the generally high average levels found in the sample. The convergence rate for meta-efficiency and TGR are 14.9% and 13.8% per year respectively, which correspond to a half-life of 4.3 and 4.6 years. In other words while banking industries within the Eurozone are relatively close to their steady state in cost efficiency, they require longer reaching their steady state in TGR, and thus overall meta-efficiency. Furthermore, the significance of the dummies suggests that these levels are different across countries. [21]

Overall the results imply that technological spillovers between banking industries do exist. Banks are not only moving progressively closer to full efficiency, but also toward the use of the best technology, although the latter is taking place more slowly than the former. However the speed at which they do so varies, with all tests suggesting that differences across banking industries persist with each moving towards its own steady state level of productivity.

< Insert Table 10 around here>

6. Final Remarks

The aim of this study is to test whether the creation of a single market for financial services fostered bank productivity growth, and if so, whether this varies across the banking industries of respective member states. Furthermore, this study aims to uncover the underlying mechanisms driving productivity, and explore the extent to which bank productivity converges across time and space.

The econometric analysis comprises the estimation of a parametric meta-frontier TFP Divisia index to measure productivity change, and a series of convergence tests to assess whether banking industries in different countries are moving towards the best available technology and efficiency. Our results suggest that productivity growth has occurred in Eurozone banking industries up to the onset of the financial crisis, but has since reversed.

[20] To conserve space, the estimates of the country specific dummies are not reported. These are available from the authors upon request.

Banking industries within the Eurozone converge toward the best available technology. The speed of convergence in productivity accelerates after the introduction of the single currency, before decreasing after the onset of the financial crisis. Technological spillovers between different Eurozone banking industries exist, and have led to progression toward the best technology. However, convergence is not complete, and significant long run differences between Eurozone banking industries persist. Improvements in technology are increasingly driven by a smaller number of banks and concentrated in fewer banking industries. These findings suggest that advances in technology and regulatory change favoured a small number of banks and therefore increased differences between banks within the Eurozone (particularly since the introduction of the single currency). This suggests that recent calls for a banking union in the Eurozone are premature, and should only be considered after careful consideration of persistent differences in the underlying production technologies which face banks in different countries.

The findings of our study are limited to the extent that too little data exists to allow us to examine the medium term effects of the on-going sovereign debt crisis, or the effects of the proposed banking union on bank productivity growth. This represents an interesting avenue for further research.

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Table 1
Aggregate Balance Sheet Information for Commercial Banks

	Austria	*Belgium*	*France*	*Germany*	*Greece*	*Italy*	*Netherlands*	*Portugal*	*Spain*	*Eurozone 9*
Total n. of bank obs. (1992 - 2009)	308	287	1310	861	246	1168	258	211	645	5294
Asset size										
- 1992	1926	2339	898	764	3267	2233	1980	5220	2390	1740
- 1999	929	2456	1012	507	2453	1322	2573	8040	2494	1385
- 2009	1542	8602	1821	676	5490	3438	3414	10439	14066	2907
Total Loans										
- 1992	1183	1182	509	418	1011	968	999	1551	1280	825
- 1999	655	876	474	325	2291	794	1241	4259	1976	751
- 2009	687	6201	1453	354	18430	2511	1794	8700	12121	2018
Other Earning Assets										
- 1992	617	1471	307	413	1725	824	921	2875	879	659
- 1999	300	1432	342	206	2590	502	1150	3049	846	508
- 2009	470	2134	358	259	6566	514	1349	1115	2327	719
Fixed Assets										
- 1992	41.6	27.9	10.0	8.8	64.4	56.8	8.6	136.5	53.2	27.2
- 1999	25.9	32.3	9.7	8.5	68.6	23.9	13.8	93.9	64.6	17.2
- 2009	13.3	30.6	16.5	6.2	210.2	29.3	45.5	55.9	122.5	23.8
Equity/Assets										
- 1992	0.054	0.033	0.054	0.081	0.042	0.078	0.050	0.071	0.080	0.061
- 1999	0.047	0.045	0.052	0.064	0.054	0.084	0.068	0.069	0.064	0.065
- 2009	0.073	0.053	0.058	0.060	0.061	0.082	0.080	0.074	0.060	0.067
Diversification Index										
- 1992	0.694	0.711	0.645	0.698	0.713	0.863	0.714	0.878	0.826	0.777
- 1999	0.572	0.692	0.615	0.630	0.909	0.723	0.788	0.773	0.684	0.685
- 2009	0.630	0.815	0.443	0.631	0.507	0.457	0.732	0.282	0.505	0.533

Note: The Table presents descriptive statistics (median values) for all banks in our sample at the beginning of the sample period (1992); at the introduction of the single currency (1999); and at the end of the sample period (2009). Values are in euro billion. All data are deflated using 2005 as the base year.

Table 2
Main results from the country-specific stochastic frontiers, 1992-2009

	AT	BE	FR	GER	GR	IT	NL	PT	SP
ey1	0.556	0.436	0.569	0.525	0.561	0.587	0.437	0.534	0.602
ey2	0.409	0.565	0.412	0.442	0.429	0.414	0.526	0.456	0.375
ew1	0.605	0.682	0.512	0.537	0.592	0.377	0.583	0.650	0.552
ew2	0.126	0.177	0.275	0.242	0.219	0.374	0.223	0.193	0.278
ew3	0.269	0.141	0.212	0.222	0.188	0.249	0.194	0.157	0.170
EFF	0.970	1.000	0.967	0.935	0.952	0.957	0.957	0.943	0.966
	(0.002)	(1.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Euro	-0.051	-0.072	-0.183	-0.194	-0.106	-0.096	0.020	-0.122	0.060
	(0.011)	(0.000)	(0.001)	(0.000)	(0.787)	(0.000)	(0.122)	(0.000)	(0.042)
D07	-0.001	-0.008	0.009	-0.035	0.066	0.056	0.033	-0.014	0.053
	(0.968)	(0.498)	(0.537)	(0.010)	(0.007)	(0.000)	(0.094)	(0.625)	(0.000)
Div. index	-0.083	-0.084	-0.090	-0.103	-0.062	-0.074	-0.134	-0.114	-0.102
	(0.019)	(0.000)	(0.000)	(0.000)	(0.020)	(0.000)	(0.001)	(0.023)	(0.000)
Eq/assets	0.094	-0.709	-0.658	-0.421	-0.441	-0.355	-1.023	0.735	-0.530
	(0.041)	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)
Fixed assets	0.016	-0.004	0.013	0.013	-0.005	0.006	0.011	0.020	0.013
	(0.000)	(0.188)	(0.000)	(0.000)	(0.605)	(0.017)	(0.040)	(0.114)	(0.000)

The Table reports the main summary results from the estimation of Equation (1) for each country in the sample. The following results are reported; ey1= elasticity of costs with respect to loans; ey2= elasticity of costs with respect to other earning assets; ew1= elasticity of costs with respect to labour; ew2= elasticity of costs with respect to deposits; ew3= elasticity of costs with respect to other administrative expenses; EFF = average efficiency score; Euro = the coefficient of the Euro intercept dummy variable; D07 = dummy for the financial crisis; Div. index = diversification index; Eq/assets = capital to assets ratio (a proxy of risk); Fixed assets = a proxy of size. The p-values are reported in parentheses. The p-value of Euro refers to the joint test of significance of all the 5 Euro dummies, as it is more representative of the significance of the effect of the introduction of the common currency.

Table 3
Country- Level Divisia Indices: Total Factor Productivity Change and its Components

Countries	*Years*	TFP^k	SC^k	TC^k	EX^k	$ALLC^k$	EC^k
Austria	1992-1998	1.005	1.001	1.009	0.998	0.997	1.001
	1999-2006	1.007	1.003	0.996	1.007	1.001	1.000
	2007-2009	0.998	1.004	0.987	0.992	0.998	0.998
	1999-2009	1.000	1.004	0.994	1.003	1.000	0.999
	1992-2009	1.002	1.003	0.999	1.001	0.999	1.000
Belgium	1992-1998	1.002	1.000	1.001	1.000	1.001	1.000
	1999-2006	1.010	1.000	0.999	1.009	1.001	1.000
	2007-2009	1.008	1.000	0.995	1.009	1.003	1.000
	1999-2009	1.009	1.000	0.998	1.009	1.002	1.000
	1992-2009	1.007	1.000	0.999	1.006	1.001	1.000
France	1992-1998	1.000	1.000	1.003	0.999	0.999	0.999
	1999-2006	1.024	1.001	1.011	1.012	1.001	0.999
	2007-2009	1.012	1.001	1.018	0.994	1.000	0.999
	1999-2009	1.021	1.001	1.013	1.007	1.001	0.999
	1992-2009	1.013	1.001	1.010	1.004	1.000	0.999
Germany	1992-1998	1.006	1.001	1.024	0.985	0.995	1.000
	1999-2006	1.025	1.001	1.000	1.023	1.002	0.998
	2007-2009	0.987	1.001	0.983	1.014	0.999	0.991
	1999-2009	1.015	1.001	0.996	1.021	1.001	0.996
	1992-2009	1.012	1.001	1.006	1.008	0.999	0.997
Greece	1992-1998	1.004	1.000	0.994	1.005	1.002	1.002
	1999-2006	1.019	1.002	1.004	1.012	1.001	1.000
	2007-2009	1.014	1.001	1.019	0.990	1.003	1.001
	1999-2009	1.018	1.001	1.008	1.006	1.002	1.000
	1992-2009	1.013	1.001	1.003	1.006	1.002	1.001
Italy	1992-1998	1.019	1.000	1.032	0.993	0.995	1.000
	1999-2006	1.008	1.002	1.026	0.986	0.998	0.998
	2007-2009	1.019	1.001	1.028	0.988	1.000	1.004
	1999-2009	1.011	1.000	1.026	0.987	0.999	0.999
	1992-2009	1.014	1.000	1.028	0.989	0.997	1.000
Netherlands	1992-1998	0.997	1.003	1.018	0.983	0.992	1.001
	1999-2006	1.010	1.005	1.027	0.973	1.005	1.001
	2007-2009	0.975	1.004	1.034	0.959	0.988	0.990
	1999-2009	1.001	1.005	1.029	0.969	1.000	0.998
	1992-2009	0.999	1.004	1.025	0.974	0.997	0.999
Portugal	1992-1998	1.012	1.002	1.019	0.982	1.005	1.005
	1999-2006	1.037	1.002	1.023	1.000	1.002	1.011
	2007-2009	1.013	1.002	1.019	0.986	1.001	1.005
	1999-2009	1.030	1.002	1.022	0.996	1.002	1.009
	1992-2009	1.024	1.002	1.021	0.991	1.003	1.008
Spain	1992-1998	0.993	1.001	0.999	0.999	0.997	0.998
	1999-2006	1.001	1.003	1.008	0.990	1.002	0.998
	2007-2009	1.008	1.001	1.025	0.990	0.983	1.010
	1999-2009	1.008	1.003	1.012	0.991	1.002	1.000
	1992-2009	1.003	1.002	1.007	0.994	1.000	0.999

Note: The Table reports the results of the estimation of the Divisia indices of Total Factor Productivity (TFP) change at the single-country level (indicated by the superscript *k*). The Divisia index is computed using Equation (2), which in turn uses the coefficients derived from the estimation of the translog Stochastic Frontiers specified in Equation (1). In the Table, TFP^k is decomposed into five components: scale efficiency change (SC^k); technical change (TC^k); changes due to environmental factors (EX^k); changes in allocative efficiency ($ALLC^k$); changes in cost efficiency (EC^k). For presentational purposes the original positive and negative growth rate values of the Divisia index have been transformed into growth values respectively larger or smaller than 1. Values larger than 1 indicate increases in productivity; values smaller than 1 indicate decreases in productivity.

Table 4
Meta-frontier Divisia Index: Total Factor Productivity Change and its Components

Countries	*Years*	*TFP**	*SC**	*TC**	*EX**	*ALLC**	*EC**
Austria	1992-1998	1.012	1.000	1.021	1.001	0.989	1.001
	1999-2006	1.010	0.999	1.007	0.999	1.005	0.999
	2007-2009	0.979	0.999	1.015	1.002	0.966	0.998
	1999-2009	1.008	0.999	1.009	0.999	1.001	0.999
	1992-2009	1.008	1.000	1.013	1.000	0.995	1.000
Belgium	1992-1998	1.015	0.999	1.023	1.003	0.989	1.000
	1999-2006	1.012	1.000	1.011	1.001	1.000	1.000
	2007-2009	0.937	1.000	1.015	0.992	0.931	1.000
	1999-2009	1.000	1.000	1.012	0.998	0.989	1.000
	1992-2009	1.006	1.000	1.016	1.000	0.990	1.000
France	1992-1998	1.013	1.000	1.020	1.002	0.993	0.999
	1999-2006	1.002	1.000	1.005	0.999	1.000	0.998
	2007-2009	0.976	1.001	1.009	0.994	0.972	1.000
	1999-2009	1.000	1.000	1.006	0.998	0.998	0.999
	1992-2009	1.005	1.000	1.011	0.999	0.996	0.999
Germany	1992-1998	1.015	1.000	1.021	1.005	0.989	1.000
	1999-2006	1.002	1.000	1.007	1.001	0.999	0.995
	2007-2009	0.985	0.999	1.010	1.004	0.975	0.997
	1999-2009	1.002	1.000	1.008	1.002	0.998	0.994
	1992-2009	1.006	1.000	1.013	1.003	0.994	0.998
Greece	1992-1998	1.017	0.999	1.022	1.004	0.990	1.002
	1999-2006	0.990	1.000	1.012	0.988	0.989	1.000
	2007-2009	0.982	1.001	1.012	0.991	0.982	0.997
	1999-2009	0.993	1.001	1.010	0.985	0.994	1.003
	1992-2009	1.003	1.000	1.015	0.994	0.993	1.001
Italy	1992-1998	1.015	0.999	1.022	0.999	0.994	1.000
	1999-2006	0.993	1.000	1.004	0.990	1.002	0.998
	2007-2009	0.982	0.999	1.011	0.992	0.979	1.002
	1999-2009	0.996	1.000	1.005	0.990	1.000	1.000
	1992-2009	1.002	1.000	1.012	0.993	0.998	1.000
Netherlands	1992-1998	1.022	0.999	1.022	1.008	0.992	1.001
	1999-2006	1.012	0.998	1.013	0.990	1.007	1.003
	2007-2009	0.937	1.000	1.016	0.982	0.955	0.984
	1999-2009	1.002	0.999	1.014	0.990	1.001	0.999
	1992-2009	1.008	0.999	1.017	0.997	0.997	0.999
Portugal	1992-1998	1.012	1.000	1.024	1.003	0.982	1.004
	1999-2006	1.021	1.000	1.013	0.992	1.006	1.010
	2007-2009	1.010	1.000	1.015	0.992	0.987	1.016
	1999-2009	1.022	1.000	1.013	0.991	1.009	1.009
	1992-2009	1.018	1.000	1.017	0.996	0.998	1.007
Spain	1992-1998	1.002	1.000	1.022	0.997	0.986	0.998
	1999-2006	1.002	1.000	1.003	0.988	1.014	0.997
	2007-2009	0.968	1.000	1.014	0.980	0.964	1.010
	1999-2009	1.005	1.000	1.006	0.985	1.014	1.000
	1992-2009	1.004	1.000	1.012	0.990	1.002	0.999

Note: The Table reports the results of the estimation of the Divisia indices of Total Factor Productivity (TFP*) change at the Eurozone level. The Divisia index is computed using Equation (2), which in turn uses the coefficients derived from the estimation of the meta-frontier (indicated by the superscript *) using Equations (4) and (5). TFP change is decomposed into its five components: scale efficiency change (SC*); technical change (TC*); changes due to environmental factors (EX*); changes in allocative efficiency (ALLC*); changes in cost efficiency (EC*). For presentational purposes the original positive and negative growth rate values of the Divisia index have been transformed into growth values respectively larger or smaller than 1. Values larger than 1 indicate increases in productivity; values smaller than 1 indicate decreases in productivity.

Table 5
Technical Gap Ratios, Cost Efficiency and Meta-efficiency

	TGR	*Cost efficiency*	*Meta-efficiency*
Austria			
1992-1998	0.888	0.969	0.860
1999-2009	0.787	0.970	0.764
1992-2009	**0.838**	**0.970**	**0.812**
Belgium			
1992-1998	0.810	1.000	0.810
1999-2009	0.704	1.000	0.704
1992-2009	**0.757**	**1.000**	**0.757**
France			
1992-1998	0.857	0.967	0.829
1999-2009	0.786	0.967	0.760
1992-2009	**0.822**	**0.967**	**0.795**
Germany			
1992-1998	0.872	0.939	0.819
1999-2009	0.818	0.932	0.763
1992-2009	**0.845**	**0.935**	**0.791**
Greece			
1992-1998	0.869	0.950	0.826
1999-2009	0.770	0.953	0.735
1992-2009	**0.820**	**0.952**	**0.780**
Italy			
1992-1998	0.925	0.961	0.889
1999-2009	0.903	0.953	0.861
1992-2009	**0.914**	**0.957**	**0.875**
Netherlands			
1992-1998	0.786	0.964	0.757
1999-2009	0.709	0.953	0.675
1992-2009	**0.747**	**0.958**	**0.716**
Portugal			
1992-1998	0.866	0.944	0.817
1999-2009	0.833	0.941	0.784
1992-2009	**0.850**	**0.943**	**0.801**
Spain			
1992-1998	0.863	0.971	0.838
1999-2009	0.828	0.961	0.795
1992-2009	**0.845**	**0.966**	**0.817**

Note: The Table reports the results of the estimation of the meta-frontier for every country over the entire sample period (1992-2009) as well as in two sub-periods (before and after the introduction of the common currency). Results are presented for the following scores: the Technical Gap Ratio (TGR), the cost efficiency level and the meta-efficiency score. Recall that the TGR measures the distance between the country specific frontier and the meta-frontier, with values closer to 1 indicating a closer proximity between the two and vice versa. The cost efficiency level is the distance of banks from their country-specific frontier and measures how efficiently banks perform their operations using their country-specific technology but not necessarily the best available technology. The meta-efficiency score is the product of the two and measures the distance from the meta-frontier.

Table 6
Proportion of Technology Leaders in Each Country

	1992-1998	*1999-2009*
Austria	0.08	0.01
Belgium	0.02	0.00
France	0.14	0.01
Germany	0.12	0.20
Greece	0.02	0.01
Netherlands	0.02	0.02
Italy	0.51	0.70
Portugal	0.03	0.06
Spain	0.06	0.00
Proportion of Technology leaders	0.10	0.05
Total number of technology leaders	248	152
Total number of banks	2402	2822

Note: The Table reports the proportion of "technology leaders" in each country derived from the estimation of the meta-frontier. A technology leader is defined as a bank with a TGR value ≥ 0.95. Recall that TGR values are computed for each bank in the sample and they are a measure of the distance between the country frontier and the meta-frontier, with values closer to 1 indicating a closer proximity and vice versa. The average TGR score is therefore a measure of how close each country is to adopting the best available technology. A technology leader is a bank that adopts the best technology and therefore contributes to the progress of the meta-frontier at the Eurozone level.

Table 7

Catch-up indices of technological change

	1992-1998 (a)	1999-2006 (b)	Change (a) to (b)	2007- 2009 (c)	Change (b) to (c)	1999-2009 (d)	Change (a) to (d)
Austria	1.012	1.012	=	1.029	↑	1.016	↑
Belgium	1.022	1.012	↓	1.020	↑	1.014	↓
France	1.017	0.993	↓	0.990	↓	0.993	↓
Germany	0.996	1.008	↑	1.030	↑	1.014	↑
Greece	1.027	1.006	↓	0.991	↓	1.003	↑
Italy	0.991	0.979	↓	0.982	↑	0.980	↓
Netherlands	1.004	0.986	↓	0.982	↓	0.985	↓
Portugal	1.005	0.990	↓	0.997	↑	0.992	↓
Spain	1.023	0.994	↓	0.990	↓	0.993	↓

Note: The Catch Up index measures the speed of convergence of national frontiers toward the meta-frontier. It is computed as the ratio of the technical change of the meta-frontier to that of the national frontier between two points in time. An increase of the index over time implies a reduction in the speed of catch-up, and vice versa.

Table 8

Panel unit root tests for convergence

Test	Specification	Statistic	p-value
Levin Lin Chu	1 lag, no time trend	Adj t*: -1.5095	0.0656
Fisher-type;	1 lag, panel no time trend	Inv. X^2 P: 37.3686	0.0047
		Inv. Norm Z: - 3.3381	0.0004
		Inv. Logit L*: -3.1875	0.0012
		Mod. Inv X^2: 3.2281	0.0006
Hadri LM	No time trend, het. Robust	Z: 19.3918	0.0000

Note:

The null hypothesis in the Levin-Lin-Chu test is non-stationarity. The alternative is that all the series are stationary and share the same autoregressive coefficient. We find stationarity and hence convergence with a 6.5% level of significance.

The Fisher type test consists of a combination of the p-values obtained from separate unit root tests performed on each of the panels. Following Choi (2001) this is performed using four methods, two based on an inverse χ^2 (the second one valid if N goes to infinity, so less relevant here), one on an inverse normal, and one on an inverse logit. The null in Fisher-type test is again of non-stationarity but the alternative allows for stationarity with different autoregressive coefficients. Again we find stationarity and hence convergence at much higher level of significance than in the LLC test, as expected since the alternative is more flexible.

Finally the Hadri LM test (2000) tests for the hypothesis that all series are (trend) stationary against the alternative that at least one has a unit root. We reject the null and conclude that at least one of the series has a unit root (i.e. convergence is taking place, but not across all countries or in the same way). The inference remains the same under different specifications regarding the existence of a time trend.

Table 9

ADF unit root test of convergence

	Lambda λ	p-value	Constant term γ	p-value
Austria	0.651	0.09	-0.005	0.13
Belgium	0.69	0.08	-0.005	0.179
France	0.91	0.13	0.000	0.411
Germany	0.965	0.356	0.002	0.142
Greece	0.927	0.284	0.000	0.839
Italy	0.73	0.05	0.004	0.098
Netherlands	0.887	0.13	0.002	0.144
Portugal	0.84	0.09	0.000	0.410
Spain	0.859	0.13	0.000	0.570

Note: The Table reports the results of the Augmented Dickey Fuller test (with one lagged difference term) for a unit root performed on Equation (11), which is estimated for each of the nine banking industries. The existence of a unit root, which is found if the coefficient λ is not significant, indicates that there are no technical spillovers between the meta-frontier and the national frontier, therefore no convergence toward best technology. Convergence is found instead if $\lambda > 0$, with full convergence given by a non-significant intercept γ.
We report directly the value of λ; the corresponding p-value is the McKinnon p-value for $-\lambda$. The p-values for the intercept are based on the t-distribution.

Table 10

Long Run and Short Run Tests for *β* and *σ*-Convergence

Cost Efficiency	*Coefficient (p-value)* *Long Run*	*Coefficient (p-value)* *Short Run*
λ	-0.537 (0.00)	-0.392 (0.00)
γ_r	<0 (0.00)	<0 (0.00)
c	0.83 (0.94)	0.47 (1.00)
Meta-efficiency		
λ	-0.254 (0.00)	-0.149 (0.00)
γ_r	<0 (0.00)	<0 (0.00)
c	0.842 (0.93)	0.103 (1.00)
TGR		
λ	-0.327 (0.00)	-0.138 (0.00)
γ_r	<0 (0.00)	<0 (0.00)
c	1.044 (0.36)	0.099 (1.00)

Note: The Table reports the results of the estimation of Equations (12), (13) and (14) for β and σ convergence. β convergence is defined as a significant negative correlation between the initial values of the performance measure and its growth, and it is measured by a significantly negative coefficient λ. This is calculated both in the short run (year-by-year following the business cycle) and in the long run (as the difference in the average performance before and after the common currency). The possibility of conditional convergence is modelled by the introduction of country-specific dummy variables. Significant dummy coefficients γ_r therefore indicate conditional convergence and thus different steady states of productivity among the countries. Finally for convergence to be present also σ convergence must be found, which is defined as a significant reduction of the dispersion in performance levels between countries over time. This is measured by a non-significant c statistic, as defined in Equation (14).

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