Shareholder value and efficiency in banking

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Abstract

This paper examines shareholder value drivers in European banking focusing on the efficiency and productivity features of individual banks. In particular, we analyse the value relevance of bank cost efficiency and total factor productivity (TFP) (in all its components, including technological change, pure technical efficiency change and scale efficiency change) to see how these influence shareholder value creation in European banking. The paper focuses on the French, German, Italian and UK banking systems over the period 1995-2002 and includes both listed and non-listed banks. We find that TFP changes best explain variations in shareholder value (measured by market-adjusted returns, MAR, for listed banks and by the ratio of EVA_{bkg} to invested capital at time *t-1* for non-listed banks). In both samples, we also find that technological change seems to be the most important component of TFP influencing shareholder value creation in European banking.

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1. Introduction

This paper empirically investigates the value-relevance of determinants of shareholder value in European banking using measures of cost efficiency and productivity obtained from Data Envelopment Analysis (DEA) frontier estimations. Focussing on the French, German, Italian and UK banking systems over the period 1995-2002, we analyse the value relevance of efficiency and productivity estimates for samples of both listed banks and non-listed banks.

There is a substantial literature dealing with bank efficiency[1] and with shareholder value[2], but only few studies (e.g. Beccalli et al., 2003, Fernandez et al., 2002, Eisenbeis et al. (1999) and Chu and Lim 1998) have empirically analysed the relationship between efficiency and shareholder value. Fernandez et al., (2002) analyse the relationship between the components of productivity change (estimated using DEA) and bank stock performance using a panel of 142 banks operating in eighteen different countries between 1989 and 1998. Fernandez et al., (2002) find that market returns have a strong positive relationship with pure efficiency change and technical change, while there is a weak relationship with scale efficiency. Beccalli et al., 2003 estimate cost efficiency of a panel of European listed banks (using DEA and Stochastic Frontier Analysis - SFA) and find that changes in the prices of bank shares reflect percentage changes in cost efficiency, particularly those derived from DEA. Eisenbeis et al. (1999) analyse the ability of cost efficiency (estimated using DEA and SFA) in explaining risk-taking behaviour, managerial competence and bank stock returns. The

[1]Studies dealing with bank efficiency focus on methodological issues (e.g. Berger 1993, Altunmas and Chakravarty, 2001), others compare estimates from different methodologies (e.g. Berger and Mester 1997, Bauer et al., 1997), others estimate efficiency focussing on countries and/or financial sectors poorly analysed by previous studies (e.g. Sathye 2001, Green and Segal 2004, Fiordelisi and Molyneux 2004, Beccalli 2004), others assess the source of inefficiency and the role of environmental factors (e.g. Dietsch and Lozano-Vives 2000, Berger and De Young 2001, Chaffai et al., 2001, Carbo et al., 2004).

[2] Studies analysing shareholder value usually focuses on developing and comparing new performance measures (e.g. O'Hanlon and Peasnell 1998, Garvey and Milbourn 2000, Fernández 2002), assessing the value-relevance of different company items such performance measures, accounting information, etc. (e.g. Barth and Beaver, 2001, Holthausen and Watts 2001), modelling the link between market value with accounting values (e.g. Ohlson 1995, Felthman and Ohlson 1995, Morel 1999, Dechow et al. 1999, Lo and Lys 2000, Ahmed et al. 2000, Liu and Ohlson 2000, Biddle et al., 2001, Ota 2002).

authors estimate a negative relationship between cost inefficiency and stock returns and find that the stochastic frontier produces relatively more informative performance measures than does DEA. Chu and Lim (1998) analyse a panel of six Singapore-listed banks (over the period 1992-96) and find that percentage change in the price of bank shares reflect percentage change in profit rather than cost efficiency estimated using DEA.

Various studies have empirically analysed the relationship between efficiency and profits (e.g. Spong et al, 1995; Berger and Mester 1997; Girardone et. al. 2004) and, not surprisingly, usually find that there is a positive relationship (efficient banks are more profitable). Closely related to the efficiency studies is another strand of literature that examines productivity in banking. Stiroh (2000), for instance, finds evidence of cost productivity improvements in the US banking sector between 1991 and 1997, although these only amounted to annual cost savings of under one percent. In contrast, Berger and Mester (2003) find that cost productivity declined by 12.5% per annum over the same period, while profit productivity increased at some 16.5% annually over the same period. While these studies do not specifically examine shareholder value issues one would expect productivity improvements to be linked to shareholder value creation.

In this paper, we analyse the relationship between shareholder value and efficiency in banking analysing the value-relevance (looking both to the relative and incremental information contents)[3]

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[3] Value-relevance studies investigate the relationship between stock market values (or changes in value) and various company items (such as performance indicators, accounting and financial information, etc). These studies can be classified in relative association studies, in incremental association studies and marginal information contents studies. Relative association studies compare the relationship between stock market returns and alternative company items (such performance measures, efficiency measures, and so on). The investigation methods are usually very similar: the "value-relevance" (labelled as "relative information content") is assessed looking at difference in the adjusted R^2 of regressions, where the dependent variable is expressed as share prices or market raw- or adjusted-returns and the independent variable is the variable under investigation. In such models, the company item with the higher R^2 is described as being the more value-relevant. Incremental association studies assess the contribution provided by a company item in explaining a company's market value or market-returns given other specified variables. In these studies, an accounting measure is usually considered value-relevant (labelled as "incremental information content") if the regression coefficient is different form zero and statistically significant. Marginal information content studies evaluate whether investors' available information set is increased by the release of particular accounting information. In other words, it is assessed if value changes are associated with the release of

of a broad range of bank efficiency measures (namely, technical, allocative, scale, cost efficiency, Total Factor Productivity changes and its components) obtained using DEA. The analysis of the relationship between shareholder value and efficiency is particularly relevant for commercial banks. For example, as Greenspan (1996) notes, "you may well wonder why a regulator is the first speaker at a conference in which a major theme is maximising shareholder value… regulators share with you the same objective of a strong and profitable bank system". The changing structural landscape of banking systems and the evolving competitive environment is expected to impact on the efficiency and productivity of banking business and this one would be expected to be reflected in shareholder value creation. As such, this paper presents an insight into how bank efficiency and the main components of productivity are linked to value creation in the European banking system.

2. Methodology

The methodological approach developed aims to assess whether efficiency and productivity factors explain variation in shareholder value for a sample of listed and non-listed European banks. To test the relationship between shareholder value with TFP changes and cost efficiency, we apply the following panel data regression model[4]:

(1) $$\psi_{i,t} = \alpha_i + \varphi_t + \sum_{j=0}^{2} \beta_j X_{i,t-j} + e_{i,t}$$

specific accounting data (conditional on other information released). For a review of these studies, see Holthausen and Watts (2001).

[4] In this model, independent variables do not suffer from scale effects and, consequently, it is not necessary to deflate independent variables.

where ψ_t is the variable representing shareholder value created over the period *t*, X is the variable that we are analysing to assess its value relevance, α_i are the individual effects capturing the time-invariant effect of the un-observed characteristics of each individual on the dependent variable (unobserved heterogeneity), φ_t are time effects capturing the effect of period t which is common across individuals, $e_{i,t}$ is the random error term and sub-indices *i* and *t* refer to the individual bank and the time period, respectively[5].

For publicly listed banks, we measure shareholder value created over the period *t* using Market Adjusted Returns (MAR), i.e. the increment of equity market value (calculated considering a 12-month non-overlapping period ending four months after the firm's fiscal year) and dividend per share paid in this period, both standardised by market value of equity at the beginning of the period and net of expected rate of return. For non-publicly listed banks, we use the ratio between Economic Value Added, estimated using a procedure accounting for banking peculiarities (EVA_{bkg})[6], and the invested capital at time t-1.

The independent variables analysed (X_t) are cost efficiency and its components (namely, Technical, Allocative and Scale Efficiency) and Total Factor Productivity (TFP) changes and its components (namely, technological change, technical efficiency change, pure technical efficiency change and scale efficiency changes)[7]. These are derived from frontier estimations

[5] We run the Hausman (1978) test for assessing the assumption of no correlation between the effects and the explanatory variables. According to results obtained, we apply the fixed effects model. For further details, see Greene (1993)

[6] Economic Value Added created between period *t-1* and *t* is estimated using a procedure accounting for banking peculiarities (EVA_{bkg}). This is calculated as follows: $EVA_{bkg(t-1,t)} = NOPAT_{t-1,t} - (CI_{t-1} * K^{e}_{t-1,t})$, where NOPAT is Net Operating Profits After Tax, CI is capital invested, K_e is the estimated cost of equity capital. We undertake seven adjustments specific for banks in calculating NOPAT and Capital invested to move the book value of banks closer to their economic value[6]. These adjustments concern: 1) loan loss provisions and loan loss reserves; 2) taxes; 3) restructuring charges; 4) security accounting; 5) general risk reserves; 6) R&D expenses and 7) operating lease expenses. For further details, see Fiordelisi and Molyneux (2004)

[7] These variables are measured at time *t*, *t-1* and *t-2*. The economic rationale for using two lagged terms is that shareholder value created over the current period (*t*) is assumed to be influenced by information (such as productivity changes, cost and profit efficiency) over the last two periods (*t*, *t-1* and *t-2*), while older information is assumed to be fully captured in market prices.

using DEA[8]. We decide to examine all the components of productivity derived from the DEA estimates as these all have a different economic meaning expressing various operational features of a company. These are shown in Figure 1. Technical efficiency expresses the ability of a firm to obtain maximal outputs from a given set of inputs or of minimising inputs for a given target of outputs; allocative efficiencies refers to the ability of using the input in optimal proportions, given their respective prices and production technology; cost efficiency expresses the ability of a firm to choose inputs and/or output levels and to mix these to minimise cost, respectively; and productivity changes measure how the ratio of a bank's outputs to its inputs changes over two consecutive periods (*t* and *t+1*). Productivity change can be decomposed into technological change[9], i.e. the shift of the efficient frontier between *t* and *t+1*, and technical efficiency change[10], i.e. the change in technical efficiency between the period *t* and *t+1* by assuming a constant technology (namely, that the efficient frontier did not change over the two periods). Technical efficiency change can been further decomposed by analysing the extent to which efficiency changes between *t* and *t+1* is due to scale efficiency or to pure efficiency change (labelled as scale efficiency change and pure technical efficiency change, respectively). The value of the decomposition is that it attempts to provide information on the sources of the overall productivity change in the banking sectors.

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[8] DEA is a linear programming methodology which uses data on the input and output quantities of a group of firms to construct a piece-wise linear surface over the data points. We apply the multi-stage DEA methodology proposed by Coelli (1998)[8]. This method involves a sequence of DEA models to identify the projected efficient points. We use DEA to estimate the distances of each data point relative to a common technology in Malmquist Total Factor Productivity (TFP) index, that measures the TFP change between two data points by calculating the ratio of the distances of each data point relative to a common technology. For further details, see Annex.

[9] Technological change is the geometric mean of the shift of the frontier between two consecutive periods and, consequently, reflects improvement or deterioration in the performance of best-practice decision making units (DMUs).

[10] Technical efficiency change measures the change in the technical efficiency between two consecutive periods and, consequently, reflects the convergence towards or divergence from the best practice on part of the remaining DMUs.

By assessing the value relevance of these variables, we are able to analyse if the creation of shareholder value is generated mainly by a technical ability of the bank or the allocative ability or both.

<< INSERT FIGURE 1 >>

One criticism of this approach is that investors may look at efficiency changes over time rather than efficiency levels at a given moment. Some studies (e.g. Casu et al., 2003) recognise this issue and analyse the value relevance of change in efficiency estimates between two consecutive periods. Although shareholder value may be certainly affected by efficiency changes, it is imprecise to estimate efficiency changes by comparing efficiency estimates obtained using frontier methodologies in two different periods since efficiency estimates are obtained measuring the distance from two different efficiency frontiers. The influence of efficiency changes on shareholder value created over a period can be better analysed by focussing on scale efficiency change and pure technical efficiency change (that are estimated assuming a constant technology).

To test for the relative information content we provide regression estimates relating each individual efficiency/productivity measure with our shareholder value indicators (MAR and EVA_{bkg}) as the dependent variable. In order to investigate the incremental information content of our efficiency/productivity measures relative to shareholder value creation we focus on: 1) cost efficiency components obtained using DEA and 2) TFP change components. By testing DEA cost efficiency components, we are able to assess the information content provided by allocative efficiency and scale efficiency to the information content of technical efficiency. This test is undertaken in three steps: firstly, we assess the value relevance of technical efficiency estimated under Variable Return to Scale (TE), then we introduce in the model the allocative efficiency estimates (AE) and finally we run again the model introducing the scale efficiency estimates (SE).

We examine whether the explanatory power (adjusted R^2) of each model differs and the contribution made by additional variables. The models run are:

$$(2) \qquad \psi_{i,t} = \alpha_i + \varphi_t + \sum_{j=0}^{2} \beta_j TE_{i,t-j} + e_{i,t}$$

$$(3) \qquad \psi_{i,t} = \alpha_i + \varphi_t + \sum_{j=0}^{2} \beta_j TE_{i,t-j} + \sum_{h=0}^{2} \chi_h SE_{i,t-h} + e_{i,t}$$

$$(4) \qquad \psi_{i,t} = \alpha_i + \varphi_t + \sum_{j=0}^{2} \beta_j TE_{i,t-j} + \sum_{h=0}^{2} \chi_h SE_{i,t-h} + \sum_{k=0}^{2} \delta_k AE_{i,t-k} + e_{i,t}$$

By testing TFP changes components, we are able to assess the additional information content provided by pure technical efficiency changes and scale efficiency changes to the information content of technological changes. This test is undertaken in three steps: firstly, we assess the value relevance of technological changes estimates (TECH_CH), then we introduce in the model the pure technical efficiency changes estimates (TE_CH) and finally we run again the model introducing the scale efficiency change estimates (SE_CH). The models run are:

$$(5) \qquad \psi_{i,t} = \alpha_i + \varphi_t + \sum_{j=0}^{2} b_j TECH\_CH_{i,t-j} + e_{i,t}$$

$$(6) \qquad \psi_{i,t} = \alpha_i + \varphi_t + \sum_{j=0}^{2} b_j TECH\_CH_{i,t-j} + \sum_{h=0}^{2} c_h PUTE\_CH_{i,t-h} + e_{i,t}$$

$$(7) \qquad \psi_{i,t} = \alpha_i + \varphi_t + \sum_{j=0}^{2} b_j TECH\_CH_{i,t-j} + \sum_{h=0}^{2} c_h PUTE\_CH_{i,t-h} + \sum_{k=0}^{2} d_k SE\_CH_{i,t-k} + e_{i,t}$$

4. Sample description

Our data set consists of unlisted banks (namely, commercial, cooperative and savings banks) from France, Germany, Italy and U.K. between 1995 and 2002 with financial information obtained form Bankscope and Datastream databases. For estimating TFP changes and cost efficiency, we use a cross-section sample by year[11], by country[12] and by bank category[13] as this is preferred to a panel data set or an international sample[14]. We defined bank inputs and outputs according to the value-added approach, originally proposed by Berger and Humphrey (1992), and we posit[15] that labour (measured as personnel expenses), physical capital (expressed as the average value of fixed-tangible assets) and financial capital (measured as loanable funds) are inputs, whereas demand deposits, total loans and other earning assets are outputs.

In assessing the value-relevance of TFP changes and cost efficiency, we use two samples. The first comprises only publicly listed banks (and shareholder value is measured as MAR) and the second both listed and non-listed banks (and shareholder value is measured as the ratio between EVA_{bkg} and the invested capital at time *t-1*). Our data set considers firm observations between 1995 and 2002 and we have to select samples over the following periods: 1) to analyse technical, allocative, scale and cost efficiencies, we consider the period 1997-2002[16]; 2) to test the information content of TFP changes (and its components), we consider the period 1998-2002[17].

Table 1 and 2 provides descriptive statistics for both samples used. The descriptive statistics show that listed banks have, on average, a larger size than non listed-banks. German banks are, on average, smaller than in the other three countries. This is due to the high number of cooperative

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[11] We use a cross-section sample by year since many bank observations would have been lost selecting a balanced panel data set.
[12] We prefer to use a sample of domestic banks for estimating the cost efficiency frontier since banks in the same country are more homogeneous (and comparable) than banks working in different countries.
[13] We also include various specific banks according to ownership type (namely, commercial banks and, jointly, cooperative and savings banks) since this seems to guarantee a greater homogeneity to the sample.
[14] The descriptive statistics are available from the authors on request.
[15] This selection of inputs and outputs follows the studies by Sathye (2001) and Dietsch and Lozano (2000), Aly et al. (1990) and Hancock (1986), wherein the author develops a methodology based on user costs to determine the outputs and inputs of a banking firm.
[16] We start from 1997 since we use a model with two lags
[17] We start from 1998 since we use a model with two lags and the variables are constructed considering the change between two consecutive years. As such, in 1998, we consider the term in 1998 (t), 1997 (t-1) and 1996 (t-2) and this latter term covers the change between two consecutive period (i.e. 1995-1996).

banks (about four times the number of commercial banks) in Germany. Regarding profitability, U.K. banks exhibit higher mean values of net income, ROE and ROA than banks in the other three countries.

<< INSERT TABLES 1 and 2>>

5. Results – Inside the 'Black Box'

This section discusses the results about the investigation of the value-relevance of the determinants of shareholder value focussing on the sample of the European publicly listed banks (where MAR is the dependent variable) and then for the sample of both listed and non-listed banks (where we use EVA_{bkg} as the dependent variable).

European publicly listed banks

This section outlines the main results of the analyses carried out to test the relative and incremental information content of shareholder drivers obtained analysing our sample of French, German, Italian and U.K listed banks. The relative information content refers to the association between stock market values and information of firm specific features (e.g. efficiency and productivity measures) and the incremental information content refers to the contribution provided by information of firm specific features in explaining market returns given other specified variables.

We first assess the relative information content by looking at differences in the explanatory power (adjusted R^2) of regressions where market-adjusted returns (MAR) is the dependent variable and determinant of shareholder value (namely, cost efficiency and productivity change components) are the independent variables. Table 3 reports the results of the relative information content by reporting the coefficient estimates[18] and their statistical significance (i.e. based on the t-statistic), the adjusted R-squared, the Durbin-Watson test (i.e. a test for assessing if residuals for consecutive observations are uncorrelated) and the p-values from a two-tailed statistical test (based on the F-statistic[19]) expressing the probability of making rejecting the hypothesis that the determinant of shareholder value investigated (e.g. cost x-efficiency) does not have a statistically significant impact on MAR. As such, a p-value close to 0 signals that it is very likely the factor investigated has a statistically significant impact on MAR; a p-value of 5% would express that there is a probability of 5% that the determinant of shareholder value analysed does not have a statistically significant impact on MAR, etc.

<< INSERT TABLE 3>>

According to Table 3, TFP changes have the highest relative information content among the shareholder drivers analysed since this explains about 46.0% of variation of MAR. All estimated regression coefficients are found to be positive and statistically significant at the 1% level showing that TFP improvements lead to increasing bank shareholder value. Among TFP components, we find that technological change has a higher value-relevance (31.2%) than technical efficiency change (28.7%). By decomposing this latter variable, pure technical efficiency change is found to have the highest information content (41.7%), while scale efficiency change has a substantially lower information content. All estimated regression coefficients for TFP change components (except for scale efficiency) are found to be positive and most of these are statistically significant at

[18] We omit to report the estimated coefficient of individual and time effects in order to facilitate the analysis of our findings about the shareholder drivers assessed. These results are available from the authors on request.

[19] The F-statistic tests the hypothesis that all of the slope coefficients (excluding the intercept) in a regression are zero.

the 1% level showing that positive technological changes and/or technical efficiency changes leads to greater shareholder value.

DEA cost efficiency explains 37.1% of variation of MAR (Table 3). Among its components, we find that technical and allocative efficiency have an equivalent value-relevance (39.5% and 39.3%, respectively), while scale efficiency has a substantially lower relative information content (namely, 33.7%). Most of the estimated regression coefficients for technical and allocative efficiency are positive. Since we do not find that negative estimated regression coefficients are statistically significant at least at the 10% level, while several positive coefficients are highly statistically significant, there seems to be a positive relationship between technical and allocative efficiency and shareholder value. Regarding cost efficiency, we find that estimated regression coefficients at time t and t-1 are positive, while that at time t-2 it is negative. All coefficients are found to be statistically significant at the 10% level. The positive relationship between cost efficiency and shareholder value seems to be positive since the most recent terms are positive and both positive estimated regression coefficient have a larger magnitude than that of the negative value.

We also analysed the incremental information content looking at the adjusted R^2 changes and the statistical significance of F-changes running models 2 to 7. Our analysis again focuses on: 1) cost efficiency components obtained using DEA; and 2) TFP changes components. Tables 4 report the results of the incremental information content of these shareholder value drivers. For each of these analysis, we report all coefficient estimates[20] and their statistical significance in all steps of the analysis, the adjusted R-squared of all model run in every steps of the analysis, the R-square

[20] We omit to report the estimated coefficient of dummy control variables in order to facilitate the analysis of our findings about the shareholder drivers assessed.

change[21], F change and its statistical the significance and the Durbin-Watson test of the most complete model.

<< INSERT TABLE 4>>

The analysis of TFP change components (table 4) shows that only pure technical efficiency changes provide additional information content to the explanatory power of technological changes since the adjusted R-squared increased by 12.4% (i.e. statistically significant at the 1% level). In contrast, scale efficiency changes increased R-squared by 0.4%. The poor additional information content of scale efficiency is also confirmed when scale efficiency is measured in terms of levels. The analysis of the DEA cost efficiency components (i.e. technical, allocative and scale efficiency) show that only allocative efficiency provides a statistically significant (at the 1% level) information content to that of technical efficiency (table 4).

Overall, in analysing the shareholder value creation of European listed banks, we find that TFP changes explains 46% of the variation in bank shareholder value, with technological change being the most important component..

European publicly listed and non-listed banks

This section presents the results on the relative and incremental information content of shareholders value drives obtained focussing on a larger sample of listed and non-listed banks in France, Germany, Italy and United Kingdom.

[21] R-squared change is the change in the R squared statistic that is produced by adding or deleting an independent variable. If the R^2 change associated with a variable is large, that means that the variable is a good predictor of the dependent variable.

In this section, we assess the relative information content by looking at differences in the explanatory power (expressed by the adjusted R^2) of regressions where EVA_{bkg} on invested capital at time *t-1* is this is regressed against various determinants of shareholder value (namely, cost efficiency and productivity changes). Tables 5 reports the results and shows: the coefficient estimates[22] and their statistical significance; the adjusted R-squared; the Durbin-Watson test and the p-values from a two-tailed statistical test assessing the null hypothesis that all regression coefficients are equal to zero (meaning that the determinant of shareholder value investigated do not have a statistically significant impact on EVA_{bkg} on invested capital at time *t-1.*

<< INSERT TABLE 5>>

According to our results, again TFP changes have the highest relative information content among the shareholder drivers analysed since this shareholder value driver allows us to explain about 29.3% of the variation of the ratio between EVA_{bkg} and invested capital at time *t-1.* All estimated regression coefficients are found to be positive and statistically significant at the 1% level showing that TFP improvements lead to increased bank shareholder value. Among TFP components, technological changes display greater explanatory power than technical efficiency change. By decomposing this latter variable, we observe that pure technical efficiency change has a higher information content than scale efficiency change. All estimated regression coefficients for TFP change components (except for scale efficiency) are found to be positive and statistically significant showing that positive technological changes and/or technical efficiency changes lead bank to generate shareholder value.

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[22] We omit to report the estimated coefficient of dummy control variables in order to facilitate the analysis of our findings about the shareholder drivers assessed.

DEA cost efficiency seems to be able to explain 10.4% of variation of the ratio EVA_{bkg} on invested capital at time *t-1*. Among its components, we find that technical efficiency has the highest adjusted R^2, while the other components have a substantially lower explanatory power (namely, 4.7% allocative efficiency and 7.7% scale efficiency). All estimated regression coefficients are positive and statistically significant at the 1% level showing that technical, allocative and scale efficiency have a positive influence on shareholder value.

The incremental information content is assessed looking at the adjusted R^2 changes and the statistical significance of F-changes running models 2 to 7 and tables 6 report our findings about the incremental information content of these determinants of shareholder value.

<< INSERT TABLE 6>>

The findings reported in tables 6 show that scale and allocative efficiency improve the adjusted R-squared of technical efficiency by 1.6% and 0.7%, respectively, and these three variables enable us to explain 23.0% of shareholder value variation. Table 6 suggests that pure technical efficiency changes and scale efficiency changes increased the r-squared by 7.6% and 0.8%, respectively, and these three variables enable us to explain 38.9% of shareholder value variation. As with our findings for listed banks, TFP is an important determinant of shareholder value creation in European banking, with the technological change component having the largest influence.

The discussion above has presented the results for the pooled sample of European listed and non-listed banks. We also repeat the estimation exercise for each banking system under study. A summary of the relative information content findings are given in Table 7.

<< INSERT TABLE 7>>

Across the four banking systems analysed we find that TFP changes have the highest explanatory power of variation of the ratio between EVA_{bkg} and invested capital at time *t-1* in Germany, Italy and United Kingdom. All regression coefficients in all countries are found to be positive and highly statistically significant providing evidence that productivity improvement lead to create shareholder value. By analysing the components of TFP changes, we find that technological change has a larger information content than technical efficiency change in France, Germany and United Kingdom, while in Italy technical efficiency change seem to have a superior value relevance than technological changes. The estimated regression coefficients of all TFP components (except scale efficiency) are generally positive and statistically significant in all countries. As such, it is possible to conclude for all four banking systems analysed that improvement in TFP driven by technological change seem to lead banks to generate shareholder value. One might claim that pure technical efficiency changes are found to have a value-relevance higher than technical efficiency change. The reason is probably due to limited poor relative information content of efficiency changes (common to all countries analysed): in other words, when we decompose technical efficiency into two components, we find that the influence of pure technical efficiency change is high whereas the influence of scale efficiency changes is low.

The explanatory power of cost efficiency seems to substantially change across countries. Among DEA cost efficiency components, scale efficiency is found to have always the lowest explanatory power of variation of variation of the ratio between EVA_{bkg} and invested capital at time *t-1*. In France and Germany, technical efficiency seems to have a higher value-relevance than allocative efficiency, while we note the opposite in Italy and United Kingdom.

By comparing pure technical and scale efficiency changes with, respectively, technical and scale efficiency, we observe in France, Italy and U.K that pure efficiency changes have a substantially higher ability in explaining variation of the ratio between EVA_{bkg} and invested capital at time *t-1* than that of technical efficiency. These differences seem to provide evidence that it is preferable to measuring efficiency in terms of changes (rather than levels as in DEA estimates) in assessing the value-relevance of the determinants of shareholder value.

Finally, we observe that our findings for the sample of listed and non-listed banks appear to be strongly consistent with those for the sample of only listed banks (discussed in the previous section).

6. Conclusions

This paper analyses the value-relevance of a range of shareholder value drivers, i.e. cost efficiency (in all its components, such as technical, allocative and scale efficiencies) and productivity changes (in all its components, such as technological change, pure technical efficiency change, scale efficiency change) focussing on the French, German, Italian and UK banking system over the period 1995-2002. We analyse the value-relevance of these shareholder drivers focussing on sample of both listed and non-listed banks. As such, we use two samples: the first comprises only publicly listed banks and the second both listed and non-listed banks. Our findings for both sample seems to be strongly consistent. In both samples, we found that TFP changes best explaining variations in shareholder value (measured by MAR for listed banks and by the ratio of EVA_{bkg} to invested capital at time *t-1* for non-listed banks). In both samples, technological change has a higher value-relevance than technical efficiency change and, by decomposing this latter variable, that we also find that pure technical efficiency change has a substantially higher explanatory power than scale efficiency change. Moreover, all estimated regression coefficients for all TFP change components (except for scale efficiency) are found to be positive and most of them are statistically significant at the 1% level providing evidence that technological and/or technical efficiency improvements enable banks to generate shareholder value.

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Table 1 Descriptive statistics of variables used to test the relationship between shareholder value and Malmquist TFP indices and cost efficiency in European banking (sample of "only" listed banks) between 1995 and 2002

	Total Loans*	Total Deposits*	Total Assets*	Book value of capital*	Net Income*	EVA*	ROE	ROA	EVA on invested capital	MAR
Minimum	19.0	62.5	81.1	4.1	-66.9	-1837.4	-11.85%	-0.25%	-27.3%	-71.6%
First quartile	2067.4	2608.6	3356.0	310.5	15.2	-30.3	4.4%	0.3%	-2.7%	-21.9%
Median	4884.4	5707.4	8912.7	797.0	40.3	0.4	6.9%	0.6%	0.6%	-3.1%
Third quartile	27650.4	36918.7	62128.2	3950.6	214.0	20.7	10.8%	0.8%	3.3%	16.9%
Maximum	217673.4	437571.0	682139.0	35110.3	3925.0	4260.1	45.3%	17.0%	55.6%	285.9%
Range	217654.4	437508.5	682057.9	35108.1	3991.9	6097.5	57.2%	17.3%	82.9%	357.5%
Arithmetic mean	21145.0	32316.7	48784.7	3235.7	218.7	-50.4	7.6%	0.7%	0.1%	1.5%
Standard deviation on mean	1.7	1.9	1.9	1.7	2.1	-9.4	154.1%	287.7%	7771.3%	3149.4%
Sample standard deviation	35474.4	61426.0	90965.3	5507.4	457.7	472.5	11.7%	2.1%	10.4%	46.8%

** Values are in Euro million*

	Technical efficiency (DEA)	Scale efficiency (DEA)	Allcoative efficiency (DEA)	Cost efficiency (DEA)	Technical efficiency change	Technological efficiency	Pure Techinical. efficiency change	Scale efficiency change	TFP change
Minimum	31.6%	24.7%	0.0%	0.0%	50.0%	0.0%	41.2%	50.0%	0.0%
First quartile	86.1%	74.0%	72.6%	49.3%	96.6%	97.0%	97.8%	98.0%	96.4%
Median	98.2%	90.4%	92.2%	66.9%	100.0%	99.7%	100.0%	100.0%	99.9%
Third quartile	100.0%	100.0%	100.0%	82.1%	103.8%	101.2%	102.2%	103.0%	102.2%
Maximum	100.0%	100.5%	100.0%	100.0%	264.8%	127.1%	264.5%	192.5%	188.0%
Range	68.4%	75.8%	100.0%	100.0%	214.8%	127.1%	223.3%	142.5%	188.0%
Arithmetic mean	91.6%	85.6%	84.0%	65.3%	102.5%	96.8%	101.3%	101.1%	99.4%
standard deviation on mean	13.2%	18.8%	25.1%	35.2%	19.2%	13.5%	18.5%	12.2%	16.5%
Estimated standard deviation	12.1%	16.1%	21.1%	23.0%	19.7%	13.1%	18.8%	12.3%	16.4%

Table 2 Descriptive statistics of variables used to test the relationship between shareholder value and Malmquist TFP indices and cost efficiency in European banking (sample of both listed and non listed banks) between 1995 and 2002

	Total Loans*	Total Deposits*	Total Assets*	Book value of capital*	Net Income*	EVA*	ROE	ROA	EVA on invested capital
Minimum	0.14	5.23	11.12	1.15	-533.21	-1900.08	-278.77%	-11.51%	-184.94%
First quartile	127.31	186.62	228.13	16.12	0.57	-1.57	3.04%	0.21%	-3.06%
Median	321.89	447.92	590.45	43.25	2.09	-0.21	4.90%	0.35%	-1.04%
Third quartile	940.29	1329.12	1742.93	125.63	7.09	1.02	6.97%	0.53%	1.29%
Maximum	196092.99	367133.96	499603.29	28863.31	1631.40	2059.16	72.94%	7.01%	166.50%
Range	196093.03	367133.34	499592.23	28883.22	2164.56	4120.04	363.05%	22.25%	348.95%
Arithmetic mean	1597.25	2378.83	3450.86	233.81	13.70	-3.41	4.63%	0.39%	-0.69%
Standard deviation on mean	5.35	5.84	6.45	6.40	7.26	-14.07	205.25%	168.02%	-642.94%
Sample standard deviation	7257.17	11603.94	17467.43	1107.57	67.03	89.18	9.50%	0.65%	8.81%

** Values are in Euro million*

	Technical efficiency	Scale efficiency	Allcoative efficiency	Cost efficiency	Technical efficiency change	Technological efficiency	Pure technical. efficiency change	Scale efficiency change	TFP change
Minimum	16.28%	7.86%	6.98%	2.70%	27.23%	19.13%	59.25%	33.05%	15.85%
First quartile	82.61%	95.49%	58.73%	45.95%	97.71%	98.14%	98.38%	99.14%	98.05%
Median	90.15%	98.32%	76.92%	63.53%	100.13%	99.74%	100.09%	100.00%	99.76%
Third quartile	96.54%	99.59%	90.55%	76.80%	102.44%	100.77%	101.91%	100.80%	101.31%
Maximum	100.00%	100.00%	100.00%	100.00%	211.73%	866.69%	197.43%	186.20%	899.75%
Range	83.72%	92.16%	93.02%	97.30%	184.51%	847.56%	138.18%	153.16%	883.90%
Arithmetic mean	88.19%	96.27%	70.37%	59.23%	100.51%	99.93%	100.44%	100.08%	100.30%
standard deviation on mean	12.57%	6.59%	38.10%	42.04%	8.49%	23.11%	6.92%	5.39%	23.39%
Estimated standard deviation	10.78%	6.24%	26.07%	24.91%	8.55%	23.06%	7.00%	5.41%	23.83%

Table 3 The relative information content of shareholder value drivers analysing European publicly listed banks.

Dependent variable (ψ_t) =Market Adjusted Return

	Technical efficiency			Allocative efficiency			Scale efficiency			Cost efficiency		
	T	t-1	t-2	T	t-1	t-2	T	t-1	t-2	T	t-1	t-2
Estimated Coefficients	0.215**	-0.13	0.076	0.117	0.238**	-0.161*	-0.026	0.175*	-0.052	0.177*	0.176*	-0.143*
Adj. R^2		0.395			0.393			0.337			0.371	
P-value & F-stat		0 (F=19.670)			0 (F=17.924)			0 (F=15.568)			0 (F=17.889)	
DW		1.929			1.986			1.977			1.972	
Period analysed		1997-2002			1997-2002			1997-2002			1997-2002	

The p-value reported, based on the F-test, expresses the probability of making an error rejecting the null hypothesis (i.e. all slope coefficients are equal to zero). As such, a p-value close to 0 signals that the performance measure investigated is likely to have a statistically significant impact on MAR since at least one of the estimated regression coefficients differs from zero. Broadly speaking, a p-value of 5% express that there is a probability of 5% that the performance measure investigated does not have a statistically significant impact on MAR, and so on.

//***indicate statistically significance at p<10%, p<5%, and p<1%, respectively*

	Technical Efficiency change			Technological change			Pure Technical Efficiency change			Scale Efficiency change			Total Factor Productivity change		
	t	t-1	t-2	t	t-1	t-2	t	t-1	t-2	t	t-1	t-2	t	t-1	t-2
Estimated Coefficients	0.300***	0.253***	-0.006	0.064	0.294***	0.248***	0.325***	0.312***	0.170***	-0.138	-0.066	-0.237	0.232***	0.411***	0.147***
Adj. R^2		0.287			0.312			0.417			0.199			0.460	
P-value & F-stat		0 (F=9.683)			0 (F=11.226)			0 (F=17.170)			0 (F=6.607)			0 (F=20.264)	
DW		1.949			1.968			1.977			1.918			1.916	
Period analysed		1998-2002			1998-2002			1998-2002			1998-2002			1998-2002	

The p-value reported, based on the F-test, expresses the probability of making an error rejecting the null hypothesis (i.e. all slope coefficients are equal to zero). As such, a p-value close to 0 signals that the performance measure investigated is likely to have a statistically significant impact on MAR since at least one of the estimated regression coefficients differs from zero. Broadly speaking, a p-value of 5% express that there is a probability of 5% that the performance measure investigated does not have a statistically significant impact on MAR, and so on.

//***indicate statistically significance at p<10%, p<5%, and p<1%, respectively*

Table 4 The incremental information contents of TFP changes and cost efficiency analysing European listed banks. Dependent variable (ψ_t) = Market Adjusted Return

Panel A – Estimated regression coefficients

	DEA Cost efficiency components								
	Technical Efficiency (TE)			Scale Efficiency (SE)			Allocative efficiency (AE)		
	t	*t-1*	*t-2*	*t*	*t-1*	*t-2*	*t*	*t-1*	*t-2*
Model 2	0.215**	-0.013	0.076	-	-	-	-	-	-
Model 3	0.184*	0.042	0.066	0.009	0.197*	-0.177*	-	-	-
Model 4	0.152	0.053	0.064	0.022	0.207*	-0.208*	-0.045	0.234*	-0.142
	Malmquist TFP components								
	Technological change (TECH_CH)			**Pure technical efficiency change (PUTE_CH)**			**Scale efficiency change (SE_CH)**		
	t	*t-1*	*t-2*	*t*	*t-1*	*t-2*	*t*	*t-1*	*t-2*
Model 5	0.064	0.294***	0.248***	-	-	-	-	-	-
Model 6	0.092	0.093	0.123**	0.299***	0.231***	0.126**	-	-	-
Model 7	0.073	0.123*	0.097	0.279***	0.233***	0.087	-0.053	0.002	-0.123

//***indicate statistically significance at p<10%, p<5%, and p<1%, respectively*

Panel B – Regression statistics

	DEA Cost efficiency components			
	Adjusted R^2	Adjusted R^2 change	F-change*	DW
Model 2	0.395	-	-	
Model 3	0.398	0.003	1.535	
Model 4	0.405	0.007	2.243*	1.915
	Malmquist TFP components			
	Adjusted R^2	**Adjusted R^2 change**	**F-change***	**DW**
Model 5	0.312	-	-	
Model 6	0.436	0.124	16.840***	
Model 7	0.440	0.004	1.566	1.917

//***indicate statistically significance at p<10%, p<5%, and p<1%, respectively*

Panel C – Summary of models run

(2) $$\psi_{i,t} = \alpha_i + \varphi_t + \sum_{j=0}^{2} \beta_j TE_{i,t-j} + e_{i,t}$$

(3) $$\psi_{i,t} = \alpha_i + \varphi_t + \sum_{j=0}^{2} \beta_j TE_{i,t-j} + \sum_{h=0}^{2} \chi_h SE_{i,t-h} + e_{i,t}$$

(4) $$\psi_{i,t} = \alpha_i + \varphi_t + \sum_{j=0}^{2} \beta_j TE_{i,t-j} + \sum_{h=0}^{2} \chi_h SE_{i,t-h} + \sum_{k=0}^{2} \delta_k AE_{i,t-k} + e_{i,t}$$

(5) $$\psi_{i,t} = \alpha_i + \varphi_t + \sum_{j=0}^{2} b_j TECH\_CH_{i,t-j} + e_{i,t}$$

(6) $$\psi_{i,t} = \alpha_i + \varphi_t + \sum_{j=0}^{2} b_j TECH\_CH_{i,t-j} + \sum_{h=0}^{2} c_h PUTE\_CH_{i,t-h} + e_{i,t}$$

(7) $$\psi_{i,t} = \alpha_i + \varphi_t + \sum_{j=0}^{2} b_j TECH\_CH_{i,t-j} + \sum_{h=0}^{2} c_h PUTE\_CH_{i,t-h} + \sum_{k=0}^{2} d_k SE\_CH_{i,t-k} + e_{i,t}$$

Table 5 The value relevance of TFP changes and cost efficiency analysing both listed and non-listed European banks
Dependent variable (ψ_t): EVA_{bkg} on invested capital

	Technical efficiency			Allocative efficiency			Scale efficiency			Cost efficiency		
	T	t-1	t-2	T	t-1	t-2	t	t-1	t-2	T	t-1	t-2
Estimated Coefficients	0.117***	0.271***	0.137***	0.103***	0.130***	-0.036***	0.043***	0.009	0.224***	0.145***	0.222***	-0.020**
Adj. R^2	0.207			0.047			0.077			0.104		
P-value & F-stat	0 (F=304.583)			0 (F=57.273)			0 (F=96.369)			0 (F=135.307)		
DW	1.948			2.084			2.049			2.103		
Period analysed	1997-2002			1997-2002			1997-2002			1997-2002		

The p-value reported, based on the F-test, expresses the probability of making an error rejecting the null hypothesis (i.e. all slope coefficients are equal to zero). As such, a p-value close to 0 signals that the performance measure investigated is likely to have a statistically significant impact on MAR since at least one of the estimated regression coefficients differs from zero. Broadly speaking, a p-value of 5% express that there is a probability of 5% that the performance measure investigated does not have a statistically significant impact on MAR, and so on.

//***indicate statistically significance at p<10%, p<5%, and p<1%, respectively*

	Technical Efficiency change			Technological change			Pure Technical Efficiency change			Scale Efficiency change			Total Factor Productivity change		
	T	t-1	t-2	T	t-1	t-2	t	t-1	t-2	T	t-1	t-2	t	t-1	t-2
Estimated Coefficients	0.230***	0.073***	0.091***	0.013*	0.512***	0.126***	0.293***	0.228***	0.237***	-0.076***	-0.142***	-0.088***	0.055***	0.483***	0.154***
Adj. R^2	0.094			0.305			0.235			0.060			0.293		
P-value & F-stat	0 (F=93.739)			0 (F=395.137)			0 (F=276.633)			0 (F=58.570)			0 (F=370.856)		
DW	1.925			1.906			1.943			1.850			1.972		
Period analysed	1998-2002			1998-2002			1998-2002			1998-2002			1998-2002		

The p-value reported, based on the F-test, expresses the probability of making an error rejecting the null hypothesis (i.e. all slope coefficients are equal to zero). As such, a p-value close to 0 signals that the performance measure investigated is likely to have a statistically significant impact on MAR since at least one of the estimated regression coefficients differs from zero. Broadly speaking, a p-value of 5% express that there is a probability of 5% that the performance measure investigated does not have a statistically significant impact on MAR, and so on.

//***indicate statistically significance at p<10%, p<5%, and p<1%, respectively*

Table 6 The incremental information contents of TFP changes and cost efficiency analysing European listed and non-listed banks. Dependent variable (ψ_t) = EVA_{bkg} on invested capital

Panel A – Estimated regression coefficients

	DEA Cost efficiency components								
	Technical Efficiency (TE)			Scale Efficiency (SE)			Allocative efficiency (AE)		
	t	t-1	t-2	t	t-1	t-2	t	t-1	t-2
Model 2	0.117***	0.271***	0.137***						
Model 3	0.098***	0.232***	0.153***	0.022*	0.007	0.123***			
Model 4	0.097***	0.224***	0.144***	0.027**	0.003	0.117***	0.061***	0.062***	-0.029***
	Malmquist TFP components								
	Technological change (TECH_CH)			Pure technical efficiency change (PUTE_CH)			Scale efficiency change (SE_CH)		
	t	t-1	t-2	T	t-1	t-2	t	t-1	t-2
Model 5	0.013*	0.512***	0.126***						
Model 6	0.018***	0.404***	0.096***	0.199***	0.160***	0.137***			
Model 7	0.017**	0.392***	0.098***	0.196***	0.159***	0.134***	-0.054***	-0.062***	-0.046***

//***indicate statistically significance at p<10%, p<5%, and p<1%, respectively*

Panel B – Regression statistics

	DEA Cost efficiency components			
	Adjusted R^2	**Adjusted R^2 change**	**F-change***	**DW**
Model 2	0.207	-	-	
Model 3	0.223	0.016	95.933***	
Model 4	0.230	0.007	44.218***	1.910
	Malmquist TFP components			
	Adjusted R^2	**Adjusted R^2 change**	**F-change***	**DW**
Model 5	0.305	-	-	
Model 6	0.381	0.076	443.654***	
Model 7	0.389	0.008	46.875***	1.936

//***indicate statistically significance at p<10%, p<5%, and p<1%, respectively*

Panel C – Summary of models run

(2) $$\psi_{i,t} = \alpha_i + \varphi_t + \sum_{j=0}^{2} \beta_j TE_{i,t-j} + e_{i,t}$$

(3) $$\psi_{i,t} = \alpha_i + \varphi_t + \sum_{j=0}^{2} \beta_j TE_{i,t-j} + \sum_{h=0}^{2} \chi_h SE_{i,t-h} + e_{i,t}$$

(4) $$\psi_{i,t} = \alpha_i + \varphi_t + \sum_{j=0}^{2} \beta_j TE_{i,t-j} + \sum_{h=0}^{2} \chi_h SE_{i,t-h} + \sum_{k=0}^{2} \delta_k AE_{i,t-k} + e_{i,t}$$

(5) $$\psi_{i,t} = \alpha_i + \varphi_t + \sum_{j=0}^{2} b_j TECH\_CH_{i,t-j} + e_{i,t}$$

(6) $$\psi_{i,t} = \alpha_i + \varphi_t + \sum_{j=0}^{2} b_j TECH\_CH_{i,t-j} + \sum_{h=0}^{2} c_h PUTE\_CH_{i,t-h} + e_{i,t}$$

(7) $$\psi_{i,t} = \alpha_i + \varphi_t + \sum_{j=0}^{2} b_j TECH\_CH_{i,t-j} + \sum_{h=0}^{2} c_h PUTE\_CH_{i,t-h} + \sum_{k=0}^{2} d_k SE\_CH_{i,t-k} + e_{i,t}$$

Table 7 The value relevance of TFP changes and cost efficiency using the sample of listed and non-listed banks: a comparison among countries

[dependent variable (ψ_t) = EVA_{bkg} on invested capital]

	FRANCE				GERMANY				ITALY				UNITED KINGDOM			
	Estimated regression coefficients and statistical significance			Value relevance	Estimated regression coefficients and statistical significance			Value relevance	Estimated regression coefficients and statistical significance			Value relevance	Estimated regression coefficients and statistical significance			Value relevance
	T	t-1	t-2		t	t-1	t-2		t	t-1	t-2		t	t-1	t-2	
Technical efficiency	(++) 1%	(++) 1%	(-) 5%	15.6%	(++) 1%	(++) 1%	(-) 1%	32.7%	(++) 1%	(++) 1%	(- -) 1%	21.3%	(- -) 1%	(- -) 10%	(++) 1%	12.7%
Allocative efficiency	(-) 5%	(++) 1%	(-) 1%	8.6%	(+) 1%	(++) 1%	(+) 1%	10.7%	(+) >10%	(++) 1%	(++) 1%	22.7%	(- - -) 1%	(+++) 1%	(-) >10%	20.9%
Scale efficiency	(+) >10%	(+) 5%	(+) 5%	7.0%	(++) 1%	(+) 1%	(++) 1%	16.5%	(-) >10%	(-) 1%	(++) 1%	14.6%	(++) 5%	(- - -) 1%	(++) 1%	12.4%
Cost efficiency	(+) 5%	(+++) 1%	(- -) 1%	20.9%	(++) 1%	(++) 1%	(+) 1%	19.6%	(+) 1%	(++) 1%	(+) 1%	28.3%	(- -) 1%	(+++) 1%	(- -) 5%	25.4%
Technical efficiency change	(++) 1%	(+) 1%	(+) 1%	8.6%	(++) 1%	(++) 1%	(+) 1%	19.0%	(++) 1%	(++) 1%	(++) 1%	21.3%	(++) 1%	(+) >10%	(+) >10%	22.6%
Technological change	(-) 10%	(+++) 1%	(+) 1%	22.7%	(+) 1%	(++) 1%	(+) 1%	22.9%	(+) 1%	(++) 1%	(+) 1%	17.2%	(++) 1%	(++) 1%	(++) 1%	30.2%
Pure technical efficiency change	(++) 1%	(++) 1%	(++) 1%	19.9%	(++) 1%	(+) 1%	(+) >10%	22.2%	(++) 1%	(++) 1%	(+) 1%	44.2%	(+) >10%	(++) 1%	(++) 1%	41.0%
Scale efficiency change	(-) >10%	(-) 1%	(+) 1%	5.0%	(-) 1%	(- -) 1%	(-) >10%	5.8%	(- -) 1%	(- -) 1%	(+) 1%	9.3%	(-) 5%	(-) 5%	(-) 1%	15.7%
TFP change	(+) >10%	(++) 1%	(++) 1%	26.9%	(++) 1%	(+++) 1%	(+) 1%	42.5%	(++) 1%	(+++) 1%	(++) 1%	38.0%	(++) 1%	(++) 1%	(++) 1%	37.4%

(+) / (++) / (+++) Estimated regression coefficient is comprised, respectively, between 0 and 0.15, between 0.151 and 0.5, between 0.51 and 1

(-) / (--) / (---) Estimated regression coefficient is comprised, respectively, between 0 and -0.15, between -0.15 and -0.5, between -0.5 and -1

Figure 1 – Efficiency and productivity changes measures

Technical Efficiency under the assumption of Variable Return to Scale	*(TE)*
Allocative Efficiency under the assumption of Variable Return to Scale	*(AE)*
Scale Efficiency	*(SE)*
Cost (or Overall) Efficiency under the assumption of Constant Return to Scale	*(CE)*
Total Factor Productivity Change	*(TFP-CH)*
Technological Change	*(TECH-CH)*
Technical Efficiency Change	*(TE-CH)*
Pure technical efficiency change	*(PUTE-CH)*
Scale Efficiency change	*(SE-CH)*

Annex

We measure cost efficiency using DEA by distinguishing between technical, allocative and scale efficiency. DEA is a linear programming methodology which uses data on the input and output quantities of a group of firms to construct a piece-wise linear surface over the data points. DEA seeks to identify the DMUs in the data set which determines an envelopment surface by solving a sequence of linear programming problems (one for each DMU in the sample). The DMUs on the frontier surface are called "technically efficient"; for each DMU not on the frontier, labelled as "technically inefficient", the efficiency score is determined by comparing its performance to the envelopment surface[23]. DEA can be either input-oriented or output oriented. In the first case, the envelopment surface is defined by seeking the maximum possible proportional reduction in input usage with output levels held constant. In the second case, DEA defines the efficient frontier by seeking the maximum proportional increase in the output production, with input levels held constant. If information on prices is available and a behavioural assumption can be appropriately made, DEA allows us to estimate allocative and cost efficiency: in the input orientation, the former refers to the combination of inputs which produces a given quantity of outputs at minimum cost, while the latter expresses the ability of a firm to choose its input and/or output levels and mix them to optimise its economic goal.

The origin of the DEA methodology can be traced back to Charnes, Cooper and Rhodes (1978), which generalised the piece-wise-linear conical hull approach to estimate the efficient frontier and radial inefficiencies scores (proposed by Farrell, 1957) to multiple outputs and

[23] The most serious DEA drawback is that this methodology does not allow for a random error due to error measurement or to good or bad luck. Therefore, the detection of outliers and influential observations is a particularly important task in DEA. The methodology applied has followed the most relevant approaches in literature and it was organised as follows: a) identification of non conforming observations (outliers) by analysing input and output data and efficiency scores; 2) "outliers" were prioritised on the basis of the underlying production process; 3) influential observations were detected by following Wilson's (1995); 4) in order to consider the masking problems, Wilson (1995) procedure was repeated by dropping all best-practice companies; 5) an individual follow-up was undertaken for the "likely" outliers and influential observations previously detected.

reformulated the optimisation process as a mathematical programming problem[24]. This model assumes that all DMUs are operating at the optimal scale level: if this assumption does not fit reality, efficiency scores calculated by solving a Constant Return to Scale (CRS) model confuses Technical Efficiency (TE) with Scale Efficiency (SE). This assumption was removed by Banker, Charnes and Cooper (1984), who added a convexity constraint to the previous model. These models, labelled as oriented models, are often solved in two stages (see Ali and Seiford 1993): the first involves a proportional contraction in inputs, while the second stage proposes a maximisation of the sum of (any remaining) slacks[25]. However, because the second stage implies the maximisation of the sums of slacks (rather than a minimisation) and the projected point obtained is not invariant to the unit of measurement, the specification of the peers and targets (necessary for the calculations of the efficiency scores) obtained in the second stage may be unsatisfactory.

To address this problem, we apply the multi-stage DEA methodology proposed by Coelli (1998). This method involves a sequence of DEA models to identify the projected efficient points and is therefore more computationally demanding than other methods[26]: however, it avoids the necessity to maximise the sum of slacks and the efficient projected points identified are invariant to units of measurement.

Because price information is available, we run the following cost minimisation DEA model:

(a1) $\min_{\lambda, x_i^*} w_i' x_i^*$,

$$\begin{aligned} \text{st:} \quad & -y_i + Y\lambda \geq 0, \\ & x_i^* - X\lambda \geq 0 \\ & N1'\lambda = 1 \\ & \lambda \geq 0 \end{aligned}$$

[24] For further details, see Seiford (1996), Førsund and Sarafoglou(2002).

[25] A problem associated with the piece-wise linear form of the frontier estimated by DEA are the "slacks", which are generated by the part of the frontier which is parallel to the axes.

[26] Such as, for example, the two-stages DEA suggested in Ali and Seiford (1993)

where w_i is a vector of input prices for the i-th firm and x_i^* (which is calculated by LP) is the cost minimising vector of input for the i-th DMU, given w_i and y_i. The total Cost Efficiency of the i-th firm is calculated as CE= $w_i'x_i^*/w_i'x_i$, which represents the ratio of minimum cost to be observed. Allocative efficiency estimates are calculated as: AE= CE/TE.

We use DEA to estimate the distances of each data point relative to a common technology in Malmquist TFP index. Total Factor Productivity (TFP) index derives from the ideas of Malmquist (1953). Total Factor Productivity (TFP) index express the change in TFP between two consecutive periods where TFP is an index of output divided by an index of total input usage[27]. We estimate the Malmquist TFP index that measures the TFP change between two data points by calculating the ratio of the distances of each data point relative to a common technology[28]. The Malmquist TFP index is the most commonly used measure of productivity change (Casu et al., 2004 p. 2525).

Let us consider two periods (*t* and *s*) and denote the output in each period as y_t and y_s , the inputs employed in each period as x_t and x_s . For each time period, let the production set S_t model the transformation of inputs into outputs. In a output-orientation[29], the Malmquist TFP change index [M_o (y_t,, X_t,, y_s,, X_s)] between *s* (the base period) and *t* is given by:

(a2) $$M_o(y_s, x_s, y_t, x_t) = \frac{d_0^t(y_t, x_t)}{d_0^s(y_s, x_s)}\sqrt{\frac{d_0^s(y_t, x_t)}{d_0^t(y_t, x_t)}\,\frac{d_0^s(y_s, x_s)}{d_0^t(y_s, x_s)}}$$

where the notation d_0^s (y_t, x_t) represents the output distance between the period *t* observation and *s* technology. A value greater than 1 will indicate positive TFP growth from s and t, whilst a value lower than 1 indicates a decline. This formulation of the Malmquist index allows us to distinguish two components of TFP change. The first (i.e. represented by the ratio outside the brackets in

[27] For further details, see Fiordelisi and Molyneux (2005).
[28] For further details, see Grosskopf (1993), Griffell-Tatjé and Lovell (1995) and Coelli (1997).
[29] In the output orientation, the productivity change between two consecutive periods refers to the firm ability to increase its outputs keeping constant its total input usage.

model a2) is the Efficiency Change (EC) that measures the change in the output-oriented measure of Farrell technical efficiency between the period s and t. The second (i.e. represented by the expression under the squared root in model a2) is the Technical Change that is the geometric mean of the shift of the frontier between s and t.

We estimate the distances of each data point relative to a common technology in TFP change using DEA[30] running the DEA-like linear programming method. Using this method, originally proposed by Fare et al., (1994), we calculate the measures previously stated by solving four DEA models under the assumption of Constant Return to Scale following Grifell-Tatjè and Lovell (1995) that notes that the TFP is not accurately estimated by assuming Variable Return to Scale for the technology. Following Fare et al., (1994), we proposed the "enhanced decomposition" by decomposing the efficient change (EC) into scale efficiency (SCC) and Pure Technical Efficiency (PTEC) components. It is important to note that all these DEA models require data for input-output quantities, but not price information. The decomposition becomes:

(a3) $$M_o(y_t, x_t, y_s, x_s) = EC \times TC = PTEC \times SCC \times TC$$

[30] A recent study of Casu et al., (2004, p.2538) measured productivity change in European banking between 1994 and 2002 using both parametric and non-parametric methodologies (namely, DEA) and found that "overall, we find that the competing methodologies do not yield markedly different results in terms of identifying the main components of productivity growth".