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Parametric Meta-Technology Frameworks to Study Technical Efficiency and Macro-Economic Effects in the European Banking System

Bilel Jarraya[1]

ABSTRACT

Bank efficiency scores usually serve as a tool for comparing institutions with each other while allowing us to quantify sub-optimal decision-making unit choices. In the case of inter-country comparisons, such differences can also arise because of macro-economic heterogeneity between countries. Previous studies estimated a common technology limit for a sample of banking institutions in different countries. The contribution of our paper is that we employ a parametric approach to specify meta-frontiers and to study the effect of macro-economic heterogeneity on banking technology development. First, we use a parametric directional distance function to specify the appropriate technology frontier for each nation and the meta-technology frontier that includes all country-specific frontiers. Then, we define the directional technology gap ratio referring to the inefficiency scores evaluated from meta-technology and country-specific technology frontiers. The estimated parameters are more significant in our model than in the general model, also called the common frontier model. Comparing the results of our model to those of common frontiers, we find a substantial variation not only in inefficiency scores but also in countries' rankings. While resorting to a pooled linear regression model, we demonstrate that the assessed technology gap ratio exhibits a significant association with inflation rates and per capita GDP. This result proves the influence of macro-economic heterogeneity on banks' efficiency and technological development.

KEY WORDS: directional meta-technology; directional technology-gap ratio; directional distance functions; banking efficiency; macroeconomic heterogeneity

JEL Classification: G21, F62, F65

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Introduction

The banking sector has basic responsibilities in any economy. It keeps the savings of different economic agents and finances business and trade projects in all sectors. Moreover, several researchers have demonstrated that the efficiency of financial institutions has a significant effect on economic growth, whereas others confirmed that bank insolvencies could be a result of economic crises, which has undesirable consequences for the whole economy. As a consequence, banks' performances are an interesting issue for diverse stakeholders, such as investors, customers, regulators, and the general public.

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Several studies that were designed to find a benchmark for banks in different countries were based on the hypothesis that these banks actually do have a common efficiency frontier. This hypothesis appears to be trivial. However, this assumption is actually strong, especially in the event of a cross-country comparison, for many reasons. In the benchmark studies, the researchers were mostly interested in banks that were the furthest from the benchmark frontier. These banks in particular may not share this common frontier. First, this could just reflect poor performance. Second, they could be too heterogeneous for comparison with a common technology; thus, we must account for heterogeneity appropriately in defining technology frontiers. Consequently, the problems of how to identify benchmarks and how to consider macro-economic divergences are crucial because this heterogeneity influences efficiency estimates substantially.

The remainder of this paper is organized as follows: The next section is a literature review of different studies that demonstrate the influence of environmental and macroeconomic divergences on banks' technology. Section three describes our methodology, while section four presents the theoretical and empirical implications. Concluding remarks are made in the final section.

Literature review

Banks represent the heart of any economy; for this reason, research studies are increasingly directed towards this sector (Hachicha & Jarraya, 2010; Jackowicz & Kowalewski, 2011; Jackowicz, Kowalewski & Kozłowski, 2011; Stefański, 2009). Several research methods can be employed for studying the banking sector. Bank performance studies and, in particular, efficiency studies of these financial institutions are among the most important methods (Berg, Førsund, & Jansen, 1992; Berger & Humphrey, 1991; Berger & Mester, 1997; Chang, Hasan & Hunter, 1998; DeYoung & Nolle, 1996; Dietsch & Lozano-Vivas, 2000; Lozano-Vivas, Pastor & Hasan, 2001; Mahajan, Rangan & Zardkoohi, 1996; McAllister & McManus, 1993; Mester, 1996; Peek, Rosengren & Kasirye, 1999; Qinyu et al., 1997). During the last decade, there has been an increase in empirical studies that estimate common frontiers for assessing and comparing bank inefficiencies between countries. However, judgments regarding inefficiencies referring to common frontiers are biased because each country has its own macroeconomic characteristics. Bank technology frontiers might necessarily be related to macroeconomic movements, such as inflation rates, monetary policy, and interest rate changes, etc. Such macroeconomic movements influence the economy as a whole and the banking sector in particular. The response and the sensitivity to these changes differ from one institution to another. Thus, these economic forces necessarily affect banks' efficiency and technological development. Consequently banks are influenced by regional economic conditions, so we cannot refer to a common frontier to compare bank inefficiency scores between countries (Bikker, 2002; Dietsch & Lozano-Vivas, 2000; Orea & Kumbhakar, 2004). Since the emergence of the X-efficiency notion with the work of Leibenstein (1966), several studies have focused on cross-country comparison of bank inefficiency (Allen & Rai, 1996; Berg et al.,1993; Pastor, Pérez & Quesada, 1997; Vander Vennet, 1994; Zago & Dongili, 2011). The relevant literature emphasizes the role of various exogenous factors in banking efficiency (Bottasso & Sembenelli, 2004; Hachicha & Jarraya, 2010; Pasiouras, 2008). So, to neglect environmental and macroeconomic heterogeneity between countries might lead to misleading and biased results (Berger et al.,2000; Chaffai, Dietsch & Lozano-Vivas, 2001; Dietsch & Lozano-Vivas, 2000; Khan and Senhadji, 2000; Lozano-Vivas et al., 2001; Lozano-Vivas, J. T. Pastor, & J. M. Pastor, 2002). For this reason subsequent studies have incorporated country-specific environmental and macroeconomic conditions (Demirguc-Kunt, Laeven & Levine, 2004; Maudos et al., 2002; Yildirim and Philippatos, 2007). Summarizing these studies, we must agree with Khan and Senhadji (2000), who in providing a review of the literature and empirical evidence of the relationship between financial development and economic growth, concluded that the results indicate that while the general effects of financial development on the outputs are positive, the size of these effects vary with the different variables considered, with indicators of financial development, and with the estimation method, the data frequency or the defined functional form of the relationship.

Therefore, overall macroeconomic conditions should affect bank efficiency. Qinyu et al. (1997) considered several reasons why cost-inefficient banks

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might tend to have loan problems. One potential reason cited by these authors is local economic downturn. Berger et al. (2000) also indicated that bank performance was sensitive to regional/macroeconomic shocks. Furthermore, they explained that bank profitability would increase during economic boom periods because all regions have likely had the unexpected favorable economic conditions. Starting from bank samples of Europe and the USA, Bos and Kolari (2005) compare the two following types of banks: large and small independent. They investigated whether the European and American banks worked under the same profit and cost frontiers. Their results demonstrated that European and American banks operate under the same profit frontiers, but the cost frontiers are different. Pasiouras (2008) provided an international investigation on the impact of regulations and supervision approaches on banks' technical efficiency. The author sampled 715 publicly quoted commercial banks dispersed in 95 countries for 2003. He used data envelopment analysis to assess technical and scale efficiencies. Then, he employed Tobit regression to estimate certain specifications while checking bank-specific features and country-level attributes, such as market structure, financial development, access to banking services, overall institutional development, and macroeconomic conditions. Pasiouras' results showed a significant effect of macro-economic conditions, such as GDP and inflation rates, on banks' technical efficiency. Oh and Lee (2010) integrated the heterogeneity of countries within groups into the Malmquist productivity index. The authors suggest that two economic agents working under two different technologies produce differently.

Battese, Rao and O`Donnell (2004) proposed a new method by which to estimate country-specific frontiers and assess efficiency scores. They built an envelope frontier, also called a meta-frontier, by enveloping a set of country-specific frontiers. This method was applied by Bos and Schmiedel (2007) to fifteen European banking markets from 1993 to 2004. This paper was based on profit and cost functions to estimate efficiency scores. The principal result of this study, compared to the pooled frontier estimations, was that meta-frontier estimations tend to overestimate efficiency scores and correlate significantly with country-specific frontiers efficiency scores. O'Donnell, Rao and Battese (2008) developed the meta-frontier concept to study efficiency differences between company groups. These groups have access to technology sets limited by the degree to which production environment and resources are regulated. The nearness of each group frontier to the constructed meta-frontier is calculated as a meta-technology ratio for each group. Their empirical illustration based on cross-country agriculture data shows that European agriculture producers work under relatively restrictive production environments. Kontolaimou and Tsekouras (2010) compared productive performance between cooperative banks and commercial and savings counterparts. They considered European banks' ownership as a source of differences. They used a meta-frontier approach to identify technology gaps between bank types and decomposed it into input and output invariant components. They demonstrated that the largest part corresponding to specific frontiers of cooperative banks is quite distant from the European meta-frontier. The authors found that the technology gap for cooperative banks was due essentially to output rather than input.

In this paper we use a parametric approach, so we model production processes based on the directional technology distance function proposed by Chambers, Chung and Färe (1996). This function characterizes banks' production technology completely. To measure efficiency while taking account of macroeconomic divergences between countries, we opt for a directional meta-technology distance function. First, we compare efficiency scores estimated by meta-technology and common technology frontiers. Second, we attempt to measure the directional technology gap ratio. This ratio allows us to detect which countries are technologically more developed in the banking industry. Finally, we explain the width of this ratio with certain macroeconomic factors while basing our study on a panel linear regression model.

Methodology

Model

Assuming a sample of K countries $k = (1,2...K)$, the banks in each country operate under a country-specific technology T^k that is defined as the set of all feasible pairs of inputs and outputs and is generally expressed as follows:

$$T^k \equiv \{(x, y) : x \geq 0, y \geq 0; x \text{ can produce } y\} \quad (1)$$

Where $x \in \Re_+^N$ denotes the input vector, while $y \in \Re_+^M$ denotes the output vector for each bank.

Hayami and Ruttan (1971) defined the meta-production function as the envelope of commonly conceived production functions. Referring to this definition, Battese et al. (2004) and Battese and Rao (2002) defined the meta-technology concept T^* as an over-arching technology, which envelops the technology of each region. The meta-technology function can be presented as follows:

$$T^* \equiv \left\{(x,y): x \in \Re_+^N, y \in \Re_+^M; x \text{ can produce } y \right.$$
$$\left. \text{at least in one country technology } T^k \right\} \quad (2)$$

The meta-technology can also be expressed as follows:

$$T^* \equiv \text{Convex Hull}\left\{T^1 \cup T^2 \cup ... \cup T^K\right\} \quad (3)$$

The technology T can be completely characterized by the directional technology distance function originally introduced by Chambers et al. (1996). This function allows banks to obtain the optimal composition of inputs and outputs by simultaneously searching the maxima of expansion and contraction of inputs and outputs, respectively. It is generally expressed as:

$$\vec{D}_{T^k}(x,y;g_x g_y) = \max\left\{\beta^k : (x - \beta^k g_x, y + \beta^k g_y) \in T^k\right\} \quad (4)$$

where β^k provides the distance between an observation (x,y) and a point on the technology frontier defined for the country k, while $g = (g_x, g_y)$ is a directional vector, with $g_x \in \Re_+^N$ and $g_y \in \Re_+^M$ establishing the direction in which technical efficiency is measured. It is generally assumed that $(g_x, g_y) = (1,1)$. In the case where $\vec{D}(x,y;g_x g_y) = 0$, a bank is considered technically efficient, whereas if $\vec{D}(x,y;g_x g_y) > 0$, a bank is assumed to be technically inefficient.

Indeed, as we have defined the meta-technology T^* above, we conceptualize the directional meta-technology distance function $\vec{D}_{T^*}(x,y;g_x g_y)$, which is assumed to be an envelope function of the directional technology distance functions of the different countries and can be expressed as follows:

$$\vec{D}_{T^*}(x,y;g_x g_y) = \max\left\{\beta^* : (x - \beta^* g_x, y + \beta^* g_y) \in T^*\right\} \quad (5)$$

For a given country k, and as a result of the meta-technology definition, we have the following:

$$\vec{D}_{T^*}(x,y;g_x g_y) \geq \vec{D}_{T^k}(x,y;g_x g_y) \quad (6)$$

We parameterize the directional distance function as Färe et al. (2005), Hachicha and Jarraya (2010) and Jarraya and Bouri (2013) did, and we opt for a quadratic flexible functional form that must satisfy the restrictions imposed by the translation property and restrictions for symmetry. Thus, the directional distance function is parameterized as follows:

$$\vec{D}(x,y;g_x,g_y,t,\theta) = \alpha_0 + \sum_{n=1}^{N}\alpha_n x_n + \sum_{m=1}^{M}\beta_m y_m +$$
$$+ 1/2\sum_{n=1}^{N}\sum_{n'=1}^{N}\alpha_{nn'} x_n x_{n'} + 1/2\sum_{m=1}^{M}\sum_{m'=1}^{M}\beta_{mm'} y_m y_{m'} +$$
$$+ \sum_{n=1}^{N}\sum_{m=1}^{M}\gamma_{nm} y_m x_n + \delta_1 t + 1/2\delta_2 t^2 + \sum_{n=1}^{N}\psi_n t x_n + \sum_{m=1}^{M}\eta_m t y_m \quad (7)$$

Usual symmetric restrictions

$$\alpha_{nn'} = \alpha_{n'n} \qquad n \neq n'$$
$$\beta_{mm'} = \beta_{m'm} \qquad m \neq m' \quad (8)$$

Restrictions imposed by the translation property

$$\sum_{m=1}^{M}\beta_m g_y - \sum_{n=1}^{N}\alpha_n g_x = -1$$
$$\sum_{n=1}^{N}\gamma_{nm} g_y - \sum_{m'=1}^{M}\alpha_{nm'} g_{x'} = 0$$
$$\sum_{m'=1}^{M}\beta_{mm'} g_{y'} - \sum_{n=1}^{N}\gamma_{nm} g_x = 0$$
$$\sum_{m=1}^{M}\eta_m - \sum_{n=1}^{N}\psi_n = 0 \quad (9)$$

where $\theta = (\alpha, \beta, \gamma, \delta, \eta, \psi)$ is the parameter vector to be estimated whereas $\varepsilon \overset{iid}{\mapsto} N(0, \sigma_\varepsilon^2)$ presents the random error term, and the trend variable explains technical progress.

In the first step, we must estimate the parameters of the frontier $\theta^k = (\alpha^k, \beta^k, \gamma^k, \delta^k, \eta^k, \psi^k)$ of each country k by using a deterministic linear programming procedure proposed by Aigner and Chu (1968). It has also been used recently by Fukuyama and Weber (2008) to estimate inefficiency and the shadow price of Japanese banks.

In a second step, using MATLAB software, we estimate the parameters of the meta-frontier

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$\theta^* = (\alpha^*, \beta^*, \gamma^*, \delta^*, \eta^*, \psi^*)$ that envelopes the estimated stochastic frontiers for the different countries.

In the third and final step, we estimate the directional technology gap ratio for each country. This index allows us to classify countries that have banks that are more efficient than others.

Battese et al. (2004) introduced the notion of the technology gap ratio in cases of output distance function and input distance function. In this paper, we will develop this concept in the case of a directional distance function, and it will be called the directional technology gap ratio.

The directional technical efficiency of each country of an observed input-output combination is defined as follows:

$$DTE^k(x,y) = \vec{D}_{T^k}(x,y;g_x g_y) \tag{10}$$

The directional technology gap ratio can be defined using the directional technology distance function from technologies T^k and T^* as follows:

$$DTGR^k(x,y) = \frac{\vec{D}_{T^*}(x,y;g_x g_y)}{\vec{D}_{T^k}(x,y;g_x g_y)} \tag{11}$$

Using the definition of directional technical efficiency, the directional technology gap ratio can be defined as follows:

$$DTGR^k(x,y) = \frac{DTE^*(x,y)}{DTE^k(x,y)} \tag{12}$$

A new decomposition of the directional technical efficiency for an observed pair (x, y) can be assessed at the meta-technology.

$$DTE^*(x,y) = DTE^k(x,y) * DTGR^k(x,y) \tag{13}$$

This equation shows that directional technical efficiency measured while referring to the meta-technology can be decomposed into the product of the directional technology efficiency assessed with reference to the country-specific technology "k" and the directional technology gap ratio between the country-specific technology "k" and the meta-technology.

The directional technology gap ratio developed above is an indicator of the distance between the directional technology frontier of the country-k and the directional meta-technology frontier. Indeed, we suggest that when the average of the directional technology gap ratio calculated for a country-k is the smallest such value, then this country is classified as technically more developed than other countries because its technology is assumed to be nearest to the meta-technology frontier.

To improve the effect of the macroeconomic divergences between European countries on the development of the banking sector, we model the directional technology gap ratio as a linear function of a set of exogenous factors presented by the macroeconomic variables. Due to our data structure, we opt for a panel linear regression. The time-invariant specific-country part of the error term is correlated with the explanatory macroeconomic variables. Likewise, while basing our approach on the *Hausman* test, we choose fixed effects regression rather than random effects regression because in our case the use of random effects regression provides biased results. The model is depicted as follows:

$$DTGR^k(x,y) = \zeta_0 + \zeta_i Z_{it} + \vartheta_{it} \tag{14}$$

where ζ_0 is the specific-country effect, Z_{it} is a vector of observed exogenous factors that are assumed to influence the directional technology gap ratio, ζ_i is a vector of parameters to be estimated and $\vartheta_{it} \overset{iid}{\mapsto} N(0, \sigma^2_{\vartheta t})$ is an error term.

Meta-frontier graph

From figure 1, in a two-dimensional plan of one input, one output, $\boldsymbol{T^*}$ presents the meta-technology frontier, $\{T^1, T^2 \ldots T^k\}$ where T^k designates the technology frontier of the country k, and $(-g_x, g_y) = (-1,1)$ is the directional vector.

Looking at the case of the frontier T^1 in figure 1, the vectors' distance $\vec{AB}$ and $\vec{AC}$ i ndicate, respectively, $\vec{D}_{T^1}(x,y;g_x g_y)$ and $\vec{D}_{T^*}(x,y;g_x g_y)$. Whereas the difference between the two vectors $\vec{AC} - \vec{AB}$ gives the vector distance $\vec{BC}$, this vector indicates the distance between the technology frontier T^1, of country 1, and the meta-technology frontier. We can explain this example as follows: to operate efficiently, bank $A(x,y)$ must reduce its input by the amount β^1 and increase its output by the same amount β^1. It will then be located at the point $B(x-\beta^1, y+\beta^1)$. Thus, this bank becomes domestically efficient, but not internationally

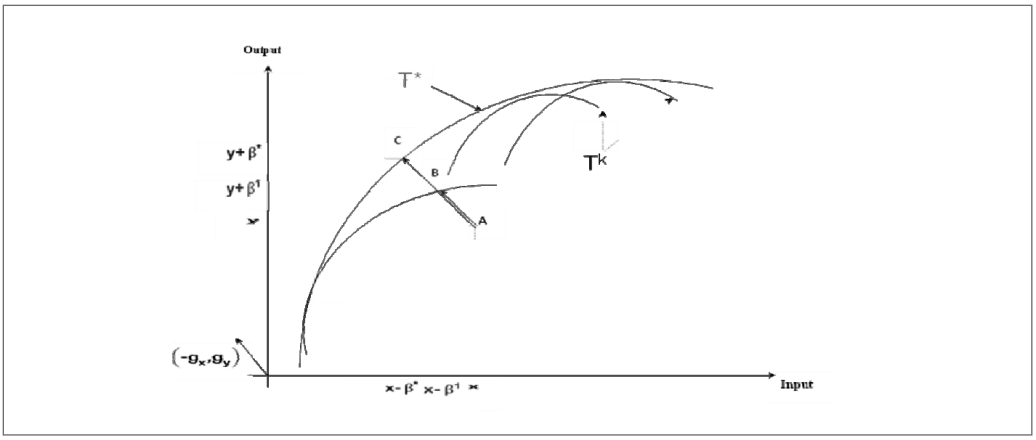

Figure 1. The directional meta-technology distance function

efficient. Indeed, to be internationally efficient, this bank $A(x, y)$ must reduce its input by the amount β^* and increase its output by the same amount β^*.

Empirical Applications

Dataset and variables definition

Having defined the methodological approach to be followed, we focus on the selection and measurement of variables. Referring to a list of European banks by country published by the European Central Bank, we construct a balanced sample of 146 banks operating in ten European countries over the period 2002-2007. All bank data were manually collected from bank accounting information and annual reports. The macroeconomic variables are collected from the International Financial Statistics Yearbook published by the International Monetary Fund. To be included in our sample, each bank must have all variables defined for our model observable for at least four years.

Input output definition

To apply our model empirically, we must specify first that inputs and outputs are used in the production process. As banks are special types of firms, it is not easy to define our set-put. Indeed, in the literature, two principal approaches can be followed: the production approach and the intermediation approach. The first is described as the value added approach proposed by Berger and Humphrey (1992). This approach is favored if branch level efficiency is calculated to investigate a bank's operational efficiency. However, in the second approach, the bank must, as a principal task, transform the maturity profiles and risks of received funds into a loan portfolio or investment of a different maturity profile and risk by using capital and labor.

In this paper, we opt for the second approach to define the set-put variables used in our study because this approach is more adequate for our banks' environment. Following Sealey and Lindley (1977), the pioneers of the intermediation approach, we specify three outputs: interbank loans, commercial loans and securities. To produce these outputs, we assume that each bank uses three inputs: fixed assets as a proxy of physical capital, personnel expenses as a measure of labor and borrowed funds.

Macro-economic variables

As in several previous studies, to control countries' macroeconomic conditions, we used the annual GDP per capita and the annual inflation rate (Hauner, 2005; Kasman & Yildirim, 2006; Maudos et al., 2002; Pastor & Serrano, 2005). According to Yildirim and Philippatos (2007), suitable economic conditions have a positive effect on the demand of supplied banking services, and this can improve banks' efficiency. Maudos et al. (2002) used the real growth rate of GDP as a proxy for market expansion. The authors demonstrated that, in an expanding market, banks achieve higher levels of profit efficiency, but they can be less efficient regarding

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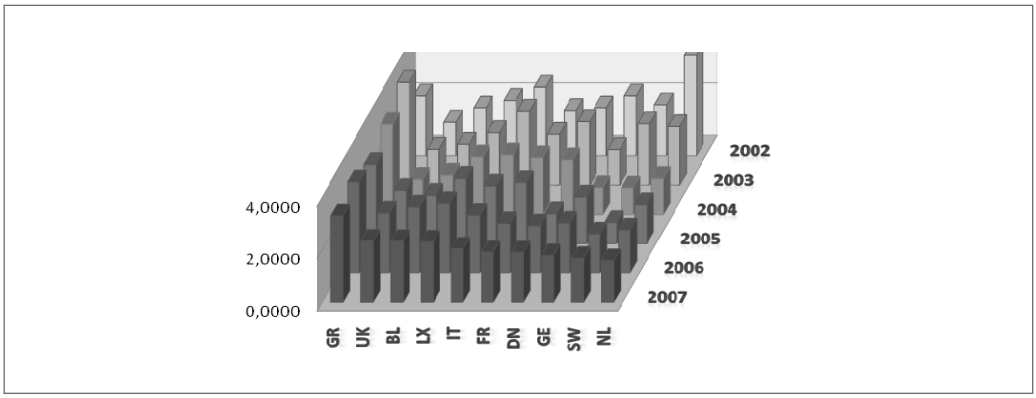

Figure 2. Inflation rate by country

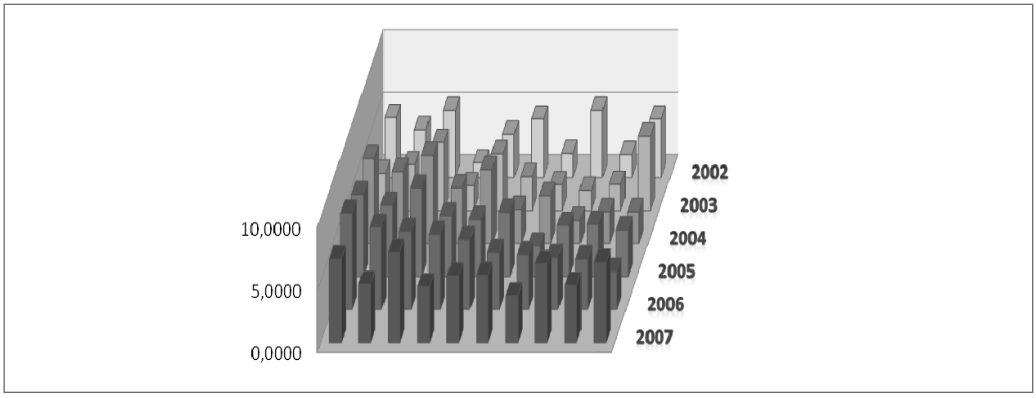

Figure 3. GDP per capita by country

their costs. Yet, Kasman and Yildirim (2006) proved that in an economy characterized by a high growth rate, banking costs are lower. Additionally, the authors demonstrated that a higher inflation rate stimulates competition between banks. Boyd, Levine and Smith (2001) agreed that high inflation rates have a negative effect on financial systems and especially on banks. However, Demirguc-Kunt et al. (2004) suggested that a high inflation rate has a meaningful, positive impact on banking margins and decreases bank costs.

Inflation rate (INFR)

The annual inflation rate measures the overall percentage increase in the consumer price index for all goods and services. The People's Bank of China uses interest rates to target inflation. They are increased if inflation is expected to rise, to reduce expenditure and borrowing by firms and households, which could raise default rates. Both will affect a bank's performance adversely. Following figure 4, the U.K. had a lower inflation rate in 2002 (1.274), although the Netherlands recorded a higher rate (3.826) for the same year. However, in 2007 Greece recorded a higher inflation rate (3.313) when compared to the Netherlands, whose inflation rate became the lowest (1.583) when compared to the other countries of our sample.

GDP_per_capita (GDPC)

This variable is defined as follows: Year Gross Domestic Product is based on purchasing-power parity (PPP) per capita GDP percentage change. In figure 6, for 2007, Greece recorded a greater percentage change in this variable; in (7.26), contrary to that of the year 2002, a greater percentage change was observed simultaneously

Table 1. Comparative analysis of QMS document development models

		Germany	France	United Kingdom	Belgium	Italy	Netherlands	Luxemburg	Sweden	Denmark	Greece
Inputs											
x_1	Mean	1556.57	10857.59	8076.65	293.57	770.01	5206.21	880.19	2790.32	493.25	786.48
	SD	2092.74	15094.19	13379.97	815.42	960.19	7703.78	1278.33	3415.19	649.03	897.59
x_2	Mean	652.17	2009.13	1471.40	197.72	184.62	2242.75	247.73	618.22	73.01	258.88
	SD	835.59	2600.15	2229.23	516.31	200.74	3305.72	322.23	702.54	83.92	268.66
x_3	Mean	84395.89	126932.2	116074.1	15051.9	9188.17	142228.5	45138.79	63464.41	6530.38	11909.7
	SD	88327.55	156274.7	170359.6	40553.8	9277.24	207420.5	57635.76	56982.95	6382.58	12784.6
Outputs											
y_1	Mean	18453.67	24052.65	13322.80	2714.15	1647.25	19956.03	15163.28	10433.81	955.26	1548.49
	SD	20588.23	29637.74	20329.70	7175.72	1976.59	28865.79	19026.03	8719.73	1151.62	1602.70
y_2	Mean	39835.54	52086.00	70056.41	6285.02	6282.93	78187.98	14481.94	41772.51	4342.65	7598.66
	SD	40758.04	63138.78	102431.5	16531.22	6403.23	115081.35	18846.36	35266.02	4210.97	7967.48
y_3	Mean	31392.92	76248.05	31974.88	7914.48	1346.05	47106.32	18373.90	12627.94	1236.64	2669.30
	SD	37500.64	106038.3	50533.30	22506.63	1959.53	67188.92	24520.39	15909.86	1266.88	3303.45
Macro-economic variables											
z_1	Mean	1.692	1.995	1.778	1.934	2.359	2.029	2.296	1.547	1.864	3.243
	SD	0.438	0.223	0.505	0.416	0.290	0.928	0.250	0.565	0.415	0.554
z_2	Mean	3.915	3.222	4.916	4.221	3.080	3.840	5.938	5.043	4.412	6.428
	SD	1.868	1.196	0.900	1.191	1.046	1.855	1.724	1.171	1.558	0.847

Notes: This table reports the mean and the cross-sectional standard deviation (SD) of each variable by country. Notations used in the table are defined as follows: x_1 = Fixed assets; x_2 = Labor; x_3 = Borrowed funds; y_1 = Interbank loans; y_2 = Commercial loans; y_3 = Securities; z_1 = Inflation rate; z_2 = GDP per_capita

in Greece and Germany (5.39). However, the smallest percentage change was recorded in the Netherlands and Italy in 2002 and 2007, respectively.

The macroeconomic variables, presented above, allow us to see a considerable economic heterogeneity between European countries. This divergence must influence the technology under which the banks of each country operate. In particular, we expect that these variables have a significant effect on the directional technology gap ratio.

Table 1 summarizes the descriptive statistics of each variable defined above. It presents the means and the standard deviations of the utilized variables. The input and output variables are expressed in millions of Euros, and the macroeconomic variables are expressed in percentages.

Results and Interpretation

For the purpose of the present study, we were interested in analyzing inter-country differences in the mean efficiency levels of European banking industries and to determine the macroeconomic divergence effect on the banking system efficiency of each country. First, we attempted to define the efficiency levels of European banks based on a common frontier by pooling the data set of all the banks, as well as on separate country-specific technologies for each European banking industry. As a result, we obtained different productive efficiency estimates for each country frontier, the meta-technology and the common technology frontiers of the banking markets (see table 2). The output and input specifications and other variables turned out to be statistically significant for both the meta-technology and common technology models.

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Table 2. Parameter estimation by frontiers and meta-frontier technology

Var.	Par	Belgium	Denmark	France	Germany	Greece	Italy	Luxemburg	Netherlands	Sweden	United Kingdom	$\vec{D}_T^*$	Prev. model
C	α_0	-0.6715	-0.6957	0.0764	-0.8989	0.0755	0.5381	-0.1529	-0.8855	0.4425	0.6018	0.6954 (0.0310)	0.0615 (0.0445)
x_1	α_1	-0.1442	4.42E-19	-0.1851	-0.1898	-0.0931	-0.0854	-0.0452	-0.1770	0.0000	-0.2293	-0.1238 (0.0033)	0.0206 (0.0048)
x_2	α_2	-0.1596	7.51E-18	-0.3010	-0.1985	-0.4006	-0.3467	-0.3866	-0.0620	-0.4501	-0.1692	-0.3463 (0.0088)	-0.0784 (0.0046)
x_3	α_3	-0.1758	-0.4828	-0.0022	-0.1034	-0.0226	-0.1237	-0.0720	-0.2393	-0.0938	-0.1407	-0.0930 (0.0013)	0.5258 (0.0031)
y_1	β_1	0.1384	-0.2701	0.0840	-0.0619	-0.0243	-0.0762	-0.0022	-0.2162	0.0270	0.0439	0.0891 (0.0027)	-0.0821 (0.0058)
y_2	β_2	-0.2060	0.1138	0.1803	-0.1424	0.0309	0.1066	0.0128	0.1176	-0.0306	0.1260	-0.0590 (0.0061)	-0.3494 (0.0033)
y_3	β_3	0.5881	0.6736	0.2476	0.7127	0.4771	0.4139	0.4855	0.6203	0.4598	0.2909	0.4068 (0.0124)	-0.1005 (0.0092)
x_1^2	α_{11}	0.0032	0.0075	-0.0032	-0.0029	-0.0115	-0.0073	0.0350	0.0137	0.0010	0.0071	0.0188 (0.0015)	-0.0021 (0.0006)
x_2^2	α_{22}	-0.0040	0.0061	-0.0049	0.0058	-0.0303	-0.0048	0.0272	0.0197	-0.0177	-0.0046	0.0062 (0.0013)	-0.0013 (0.0025)
x_3^2	α_{33}	-0.0042	-0.0335	-0.0058	-0.0091	-0.0002	0.0016	0.0170	-0.0379	0.0033	0.0019	-0.0138 (0.0004)	-0.0952 (0.0032)
y_1^2	β_{11}	-0.0137	-0.0146	-0.0212	-0.0249	-0.0167	-0.0084	0.0075	-0.0210	-0.0016	-0.0096	0.0079 (0.0014)	0.0100 (0.0243)
y_2^2	β_{22}	-0.0231	-0.0099	-0.0169	-0.0110	-0.0114	-0.0107	-0.0354	-0.0317	-0.0126	-0.0385	-0.0351 (0.0006)	-0.0137 (0.0003)
y_3^2	β_{33}	0.0378	0.0292	0.0565	0.0448	0.0781	0.0347	-0.0849	0.0429	0.0235	0.0402	-0.0011 (0.0054)	-0.0018 (0.0439)
x_1x_2	α_{12}	-0.0036	0.1150	0.0312	-0.0087	0.0423	0.0065	-0.0350	0.0216	0.0123	0.0210	0.0014 (0.0002)	0.0088 (0.0065)
x_1x_3	α_{13}	0.0042	-0.0616	-0.0169	0.0149	-0.0031	0.0046	-0.0382	-0.0128	0.0056	-0.0096	-0.0112 (0.0007)	0.0046 (0.0133)
x_1y_1	γ_{11}	-0.0050	0.0142	-0.0074	-0.0103	-0.0273	-0.0084	0.0563	-0.0367	-0.0090	-0.0053	-0.0084 (0.0008)	-0.0010 (0.0014)
x_1y_2	γ_{12}	-0.0197	-0.0948	-0.0713	-0.0411	-0.0701	-0.0706	-0.0954	-0.0204	-0.0819	-0.0428	-0.0528 (0.0009)	-0.0018 (0.0004)
x_1y_3	γ_{13}	0.0352	-0.1220	0.0383	0.0455	0.0492	0.0668	0.1225	0.0008	0.0806	0.0177	0.0671 (0.0012)	-0.0059 (0.0006)
x_2x_3	α_{23}	0.0046	-0.0332	-0.0006	-0.0001	0.0027	-0.0002	-0.0065	-0.0048	-0.0038	-0.0155	0.0003 (0.0007)	0.0858 (0.0456)
x_2y_1	γ_{21}	-0.0130	0.0311	0.0024	0.0138	-0.0007	-0.0019	0.0173	-0.0504	0.0003	0.0036	-0.0064 (0.0034)	-0.0297 (0.0127)
x_2y_2	γ_{22}	-0.0418	0.0328	-0.0048	-0.0264	-0.0086	-0.0197	-0.0338	0.0316	-0.0020	-0.0285	-0.0141 (0.0008)	-0.0543 (0.0039)
x_2y_3	γ_{23}	0.0435	0.1343	0.0242	0.0095	0.0075	0.0185	0.0454	0.0844	0.0035	0.0635	0.0445 (0.0016)	-0.0089 (0.0088)
x_3y_1	γ_{31}	0.0041	-0.0090	0.0060	0.0000	-0.0053	-0.0095	-0.0064	0.0174	-0.0002	-0.0026	0.0013 (0.0065)	-0.0036 (0.0133)
x_3y_2	γ_{32}	0.0153	-0.0077	0.0030	-0.0022	0.0019	0.0033	0.0215	-0.0395	-0.0008	0.0148	0.0019 (0.0005)	0.0769 (0.0003)
x_3y_3	γ_{33}	0.0022	0.0075	0.0077	0.0249	0.0506	0.0344	-0.0798	0.1163	0.0096	0.0007	-0.0021 (0.0004)	0.0289 (0.0022)
y_1y_2	β_{12}	0.0105	0.0279	0.0371	-0.0045	-0.0001	-0.0182	-0.0159	0.0214	-0.0004	0.0045	0.0202 (0.0006)	0.0159 (0.0013)
y_1y_3	β_{13}	0.0682	0.0293	0.0195	0.0895	0.0817	0.1113	0.1571	0.0102	0.0966	0.0753	0.0675 (0.0014)	-0.0039 (0.0005)
y_2y_3	β_{23}	-0.1002	-0.0476	-0.0736	-0.1078	-0.1289	-0.1210	-0.0771	-0.1263	-0.1039	-0.0922	-0.0870 (0.0012)	-0.0058 (0.0005)
t	δ_1	-0.0232	-0.0003	0.0160	-0.0051	0.0243	0.0129	-0.0132	0.0095	0.0276	0.0060	0.0727 (0.0020)	0.0013 (0.0203)
t^2	δ_2	-0.0003	0.0027	-0.0008	0.0010	-0.0002	0.0004	0.0048	-0.0005	-0.0013	0.0020	0.0006 (0.0149)	-0.0006 (0.0338)
tx_1	ψ_1	0.0009	0.0049	-0.0009	0.0025	0.0007	0.0012	0.0010	-0.0016	-0.0015	-0.0035	0.0031 (0.0032)	-0.0032 (0.0121)
tx_2	ψ_2	-0.0013	0.0057	-0.0010	0.0010	-0.0010	-0.0015	-0.0043	0.0011	-0.0016	0.0061	-0.0009 (0.0021)	0.0022 (0.0051)
tx_3	ψ_3	0.0010	-0.0096	0.0015	-0.0031	0.0001	-0.0002	0.0034	0.0006	0.0026	-0.0034	-0.0038 (0.0023)	0.0009 (0.0014)
ty_1	η_1	-0.0015	0.0043	0.0010	-0.0013	0.0018	-0.0016	0.0002	-0.0056	-0.0016	0.0000	0.0016 (0.0016)	0.0014 (0.0045)
ty_2	η_2	-0.0008	0.0044	-0.0014	0.0031	0.0023	0.0006	0.0007	0.0084	0.0011	-0.0010	0.0033 (0.0016)	0.00005 (0.0034)
ty_3	η_3	0.0028	-0.0078	0.0000	-0.0014	-0.0044	0.0005	-0.0008	-0.0027	0.0000	0.0001	-0.0065 (0.0007)	-0.0015 (0.0019)

Notes: Different notations used in this table are defined as follows: x_1 = Fixed assets; x_2 = Labor; x_3 = Borrowed funds; y_1 = Interbank loans; y_2 = Commercial loans; y_3 = Securities; t = trend time variable that explains technical progress.

Table 3. Efficiency estimate by country

		Belgium	Denmark	France	Germany	Greece	Italy	Luxemburg	Netherlands	Sweden	United Kingdom
						2 002					
Model 1		0,2597	0,1734	0,3661	0,2706	0,1635	0,3236	0,2421	0,1385	0,2550	0,2697
Model 2	$\vec{D}_{T^k}$	0,1799	0,1754	0,1955	0,1477	0,1510	0,2223	0,1684	0,1265	0,2515	0,1991
	$\vec{D}_{T^*}$	0,2156	0,2157	0,2648	0,1579	0,1836	0,2589	0,1924	0,1564	0,2754	0,2222
						2 003					
Model 1		0,3507	0,1697	0,2692	0,3011	0,1629	0,2870	0,3397	0,1428	0,1881	0,3124
Model 2	$\vec{D}_{T^k}$	0,1864	0,1879	0,1947	0,1721	0,1785	0,1845	0,2666	0,2315	0,1996	0,2576
	$\vec{D}_{T^*}$	0,2469	0,2546	0,2143	0,1925	0,1948	0,2512	0,2875	0,2644	0,2156	0,2929
						2 004					
Model 1		0,3449	0,1357	0,2645	0,2813	0,1592	0,2295	0,3429	0,2526	0,2907	0,2617
Model 2	$\vec{D}_{T^k}$	0,2154	0,2548	0,2211	0,1988	0,1679	0,1962	0,2532	0,2584	0,2756	0,2394
	$\vec{D}_{T^*}$	0,2234	0,2977	0,2412	0,2164	0,1865	0,2159	0,2845	0,2695	0,3003	0,2485
						2 005					
Model 1		0,2539	0,1510	0,2703	0,4095	0,3239	0,3094	0,3808	0,2847	0,2613	0,3969
Model 2	$\vec{D}_{T^k}$	0,2143	0,1945	0,2289	0,1842	0,2964	0,2005	0,2326	0,2755	0,2135	0,2248
	$\vec{D}_{T^*}$	0,2314	0,2514	0,2378	0,2151	0,3333	0,2456	0,2784	0,2994	0,2488	0,2315
						2 006					
Model 1		0,2242	0,1394	0,2814	0,3326	0,1702	0,2674	0,4327	0,1749	0,3926	0,3296
Model 2	$\vec{D}_{T^k}$	0,1738	0,2165	0,2187	0,1964	0,2136	0,1743	0,2598	0,1555	0,2544	0,2376
	$\vec{D}_{T^*}$	0,1954	0,2549	0,2333	0,2132	0,2288	0,1947	0,2797	0,1678	0,2711	0,2541
						2 007					
Model 1		0,3073	0,1468	0,2468	0,2723	0,1734	0,2337	0,3918	0,1758	0,3832	0,3260
Model 2	$\vec{D}_{T^k}$	0,2235	0,2564	0,2076	0,1764	0,2144	0,1856	0,2479	0,1598	0,2487	0,2376
	$\vec{D}_{T^*}$	0,2459	0,2945	0,2314	0,1987	0,2266	0,2007	0,2689	0,1625	0,2525	0,2544
						2002-2007					
Model 1		0,2901	0,1527	0,2831	0,3112	0,1922	0,2751	0,3550	0,1949	0,2952	0,3161
Model 2	$\vec{D}_{T^k}$	0,1989	0,2143	0,2111	0,1793	0,2036	0,1939	0,2381	0,2012	0,2406	0,2327
	$\vec{D}_{T^*}$	0,2264	0,2615	0,2371	0,1990	0,2256	0,2278	0,2652	0,2200	0,2606	0,2506

Notes: This table reports a comparison of the average annual inefficiency scores estimated by model 1 and model 2 for each country reported by year and for the whole period. Model 1 is the common technology frontier. In model 2, the inefficiency scores are assessed first, referring to the country-specific technology frontier $\vec{D}_{T^k}$. In a second stage we assess the inefficiency scores referring to the meta-technology frontier $\vec{D}_{T^*}$.

Usually, most studies estimate a common technology frontier without taking into account the different factors that can influence the various markets. These approaches did not allow us to adequately compare efficiency levels across countries. However, the meta-technology approach allowed us to properly compare technical efficiency levels and to determine potential differences between countries.

Table 2 reports the estimated parameters for country-specific technology. The last two columns of this table list the estimated parameters of the meta-technology and the common technology, respectively, using parametric linear programming. Standard errors attached to these frontiers were obtained through a parametric bootstrapping method. Treating the sample as if it were the population, we randomly drew re-

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placement for 1000 new datasets of the same size as the original sample. For each generated dataset, the new meta-frontier parameters were estimated by linear programming. Therefore, there are 1000 parameter estimates for each coefficient. The estimated standard error of a meta-frontier parameter was calculated as the standard deviation of the 1000 new parameter estimates. However, there are substantial differences between the meta-technology coefficients and the corresponding coefficients of the common technology. Moreover, we observed that the majority of the bootstrapped standard deviations of the meta-technology parameters were relatively small compared to the corresponding coefficients in the common technology. As a consequence, the estimated parameters of the meta-technology are more significant than those of the common technology.

Comparing the inefficiency scores, we found a considerable variation between the inefficiency scores assessed from the common frontier and those assessed from the meta-technology (see table 3). For example, Italian banks recorded average inefficiency scores as follows: 27.51%, 19.39%, and 22.78%, arising from the common, country-specific, and meta-technology frontiers, respectively. For most banking systems, inefficiency scores resulting from the common model seem to underestimate the efficiency level for the sample countries. As we supposed at the beginning of this study, the hypothesis of simple common technology to compare banks efficiency induces a strong bias in across-country comparisons and yields misleading results. This view is supported by prior findings in the literature (Bikker, 2002; Dietsch & Lozano-Vivas, 2000; Orea & Kumbhakar, 2004). Additionally, we note that the order of countries, while taking into account the efficiency criteria as a basis, has changed from the model of a common frontier to the meta-frontier model. The most efficient banking system is that of Denmark with an average inefficiency score of 15.27%, based on the common frontier model. Yet, based on the meta-frontier model, the most efficient banking system is that of Germany with an average inefficiency score of 19.90%. However, the Luxemburg banking system is the most inefficient in both the two models, with an average inefficiency score of 35.50% and 26.52%, calculated from the common and the meta-frontier models, respectively. But, referring to the country-specific frontiers, we note that the banking sector of Sweden is the most inefficient with an average inefficiency score of 24.06%, and that the most efficient banking system is that of Germany with an average of 17.93%. From a financial point of view, Germany and Sweden have to increase their outputs and simultaneously decrease their inputs by approximately 18% and 24%, respectively.

The directional technology gap ratio is imperative to managers, as well as to government policy-makers. This ratio assesses the possible enhancement in efficiency by changing the macro-economic conditions and production environment. In addition to macro-economic conditions, the government has the ability to change the production environment through investments in human, physical and financial capital. In comparison, managers also have the possibility to make changes in the production environment by changing the locations of agencies. Noting that country-specific technology, in extreme cases, can be only tangential to the meta-technology, in this case, the directional technology gap ratio equals one. From table 4, we note a considerable divergence between the average values of directional technology gap ratios between countries. From this table, we observed during our period of survey that the lowest value of this ratio, 1.077, is assigned to the United Kingdom, whereas the highest value of the directional technology gap ratio is 1.22 and is assigned to Germany. Consequently, the specific-technology of German banks is the most distant from the meta-technology. However, the specific-technology of the United Kingdom banking system is nearest to the meta-technology. From an economic point of view, the German banking system is technologically the least developed, whereas the United Kingdom banking system is technologically the most-developed one, compared to the other banking systems of our sample. So, governments must change the production environment and improve macro-economic conditions that favor technological development of the banking sector.

To study the effect of inter-country macroeconomic divergences on the directional technology gap ratio value, we modeled this ratio as a linear function of macroeconomic variables. From the results of table 5, we demonstrate the existence of a significant negative effect of the inflation ratio, whereas the GDP per capita growth is associated with a positive effect, and these effects were found to be significant at the 1% and 5%

Table 4. The directional technology gap ratio by country

	Belgium	Denmark	France	Germany	Greece	Italy	Luxemburg	Netherlands	Sweden	United Kingdom
					2002					
DTE^k	0,1799	0,1477	0,1955	0,1754	0,1510	0,2223	0,1684	0,1265	0,2515	0,1991
DTE^*	0,2156	0,1579	0,2648	0,2157	0,1836	0,2589	0,1924	0,1564	0,2754	0,2222
$DTGR^k$	1,1984	1,0691	1,3545	1,2298	1,2159	1,1646	1,1425	1,2364	1,0950	1,1160
					2003					
DTE^k	0,1864	0,1721	0,1947	0,1879	0,1785	0,1845	0,2666	0,2315	0,1996	0,2576
DTE^*	0,2469	0,1925	0,2143	0,2546	0,1948	0,2512	0,2875	0,2644	0,2156	0,2929
$DTGR^k$	1,3246	1,1185	1,1007	1,3550	1,0913	1,3615	1,0784	1,1421	1,0802	1,1370
					2004					
DTE^k	0,2154	0,1988	0,2211	0,2548	0,1679	0,1962	0,2532	0,2584	0,2756	0,2394
DTE^*	0,2234	0,2164	0,2412	0,2977	0,1865	0,2159	0,2845	0,2695	0,3003	0,2485
$DTGR^k$	1,0371	1,0885	1,0909	1,1684	1,1108	1,1004	1,1236	1,0430	1,0896	1,0380
					2005					
DTE^k	0,2143	0,1842	0,2289	0,1945	0,2964	0,2005	0,2326	0,2755	0,2135	0,2248
DTE^*	0,2314	0,2151	0,2378	0,2514	0,3333	0,2456	0,2784	0,2994	0,2488	0,2315
$DTGR^k$	1,0798	1,1678	1,0389	1,2925	1,1245	1,2249	1,1969	1,0868	1,1653	1,0298
					2006					
DTE^k	0,1738	0,1964	0,2187	0,2165	0,2136	0,1743	0,2598	0,1555	0,2544	0,2376
DTE^*	0,1954	0,2132	0,2333	0,2549	0,2288	0,1947	0,2797	0,1678	0,2711	0,2541
$DTGR^k$	1,1243	1,0855	1,0668	1,1774	1,0712	1,1170	1,0766	1,0791	1,0656	1,0694
					2007					
DTE^k	0,2235	0,1764	0,2076	0,2564	0,2144	0,1856	0,2479	0,1598	0,2487	0,2376
DTE^*	0,2459	0,1987	0,2314	0,2945	0,2266	0,2007	0,2689	0,1625	0,2525	0,2544
$DTGR^k$	1,1002	1,1264	1,1146	1,1486	1,0569	1,0814	1,0847	1,0169	1,0153	1,0707
					2002-2007					
DTE^k	0,1989	0,1793	0,2111	0,2143	0,2036	0,1939	0,2381	0,2012	0,2406	0,2327
DTE^*	0,2264	0,1990	0,2371	0,2615	0,2256	0,2278	0,2652	0,2200	0,2606	0,2506
$DTGR^k$	1,1383	1,1099	1,1232	1,2203	1,1081	1,1748	1,1138	1,0934	1,0831	1,0769

Notes: Different notations used in this table are defined as follows: DTE^k : the directional technical efficiency for country k ; DTE^* : the directional technical efficiency assessed from the meta-technology; $DTGR^k$: directional technology gap ratio for country *k*.

levels, respectively. In addition, the adjusted R-squared value is 0.7864, indicating that the macroeconomics variables which we utilized in our regression can explain 78.64% of the deviation of the directional technology gap ratio.

These econometric results support important economic interpretations. On the one hand, a high rate of inflation weakens the real interest rate and can induce a negative real rate if the inflation rate exceeds the nominal interest rate fixed by the central bank. A similar situation causes bank bankruptcies and consequently triggers economic crises. On the other hand, the more one improves the GDP per capita, the more the banking system is developed. Improvement of household incomes increases savings, which enhances banks' inputs; thus, their outputs and

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Table 5. Macroeconomic effect on the directional technology gap ratio

variables		Coefficients	t-ratio	Probability
INFR		-0.0030341	-2.3505	0.0238
GDPC		0.0046149	3.4468	0.0013
	Fixed Effects			
BL	0.017870			
DN	0.013012			
FR	0.112278			
GE	0.179451			
GR	0.041328			
IT	0.222131			
LX	0.244606			
NL	0.051173			
SD	0.045585			
UK	0.124611			
R-squared		0.8351		
Adjusted R-squared		0.7864		
Prob.(F-statistic)		0.000000		

turnovers will increase. Finally, the development of specific country's banks' technology is influenced by monetary and budgetary policies and the environmental features of this country.

Conclusion

Despite the construction of the European Central Bank and the creation of the European Monetary Union, the development divergence between European nations is a reality that we cannot hide. From this starting point, we observe that each country has its specific economic features. These features influence the development of each country's banking sector significantly. In fact, the technology under which the banks of a particular country operate is not the same as that of the other countries. For this reason, to study inter-country bank efficiency, it is necessary to model the specific technology for each country. Once this is achieved, we can construct an envelope technology that includes all the country-specific technologies.

Our results show first that the estimated parameters of the meta-technology frontier are more significant than those of the common technology frontier. Second, we found a significant divergence in the results between the two frontiers; the countries' rankings have changed, and most inefficiency scores are underestimated in the meta-technology approach. Third, in assessing the directional technology gap ratio, we discovered that the German banking system is technologically the least developed, whereas the United Kingdom banking system is technologically the most developed one compared to the other banking systems in our sample. Finally, the regression of this ratio on the macro-economic indicators indicates significant influence of the inflation rate and the GDP per capita. Therefore, our concluding remark regarding these regression results is that each country must minimize its inflation rate and increase its GDP per capita to ensure the technological development of its banking system and avoid possible economic crises.

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