Bank Efficiency, Productivity and Convergence in EU countries:

A Weighted Russell Directional Distance Model

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Abstract:

The objective of this study is three-fold. First we estimate and analyse bank efficiency and productivity changes in the EU28 countries with the application of a novel approach, a weighted Russell directional distance model. Second, we take a disaggregated approach and analyse the contribution of the individual bank inputs on bank efficiency and productivity growth. Third, we test for convergence in EU28 bank productivity as well as in the inefficiency of individual bank inputs. We find that bank efficiency has been undermined by the financial crisis in banks notably from the EU15 countries. We also argue that bank efficiency and productivity in EU countries vary across the banking sector with banks from the 'old' EU showing higher efficiency levels. Nonetheless, a noticeable catching up process is observed for banks from the 'new' EU countries. Consequently, we do not find evidence of group convergence for bank productivity but there is evidence of convergence in bank efficiency change and technical change among the EU28 countries throughout the period 2005-2014. The driving force seems to be convergent technical change from the old EU Member States' banks. On the other hand, almost no convergence is detected for the banks' individual inputs while the transition paths show heightened diversity during the crisis years.

JEL Classification: G21; D21; G23; C11

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1. Introduction

There has been extensive research on bank efficiency either on individual EU countries or on the group of EU countries that include 'old' EU15 and/or new EU countries, see for example, Berger, (2003), Goddard et al. (2007), Barros et al. (2007), Fries and Taci (2005), Casu and Girardone (2006), Chortareas et al (2012; 2013), Matousek et al (2014), among others.

The focal point of these empirical studies has been to find evidence on the degree of European banking markets integration. A large number of studies have specifically analysed differences at bank efficiency levels across the EU countries. Casu and Molyneux (2003), in their early study on bank integration, conclude that there is evidence that EU banks have converged. Similar results are reported by Barros at al. (2007), who stress upon the importance of country-level characteristics on bank performance. Goddard et al. (2007), on their part, argue that the integration process has implications for systemic risk and as such constitutes a challenge to the supervisory and regulatory framework. Following the most recent financial crisis, bank performance, particularly, in the 'old' EU countries have been affected by the adverse economic environment. As widely reported, governments and Central Banks across EU countries have had to bail out a large number of commercial banks in order to avoid a systemic crisis. In 2009, European governments approved $5.3 trillion of aid, a staggering amount representing more than the annual gross domestic product of Germany, to support banks during the credit crunch (Bloomberg, 2009).

This unique and unprecedented event motivates our research on the analysis of EU28 bank performance and convergence before, during, and after the crisis. We attempt to extend the current literature on the European banking markets by examining technical efficiency and productivity change in the EU 28 banking sector during the period 2005-2014. Hence, this study tries to shed light on bank performance during the financial crisis and in its aftermath.

Furthermore, as far as we are aware, there is rather limited up to date research on bank efficiency in EU countries that takes into account the current disturbances in the banking markets. Indeed, most studies on bank efficiency discuss findings that pre-date the crisis (see Altunbas (2001), Casu and Molyneux (2003), Casu and Girardone (2006), Goddard et al (2007), Barros et al (2007), Brissimis et al. (2010) among others). Our study not only addresses the above-mentioned gap but we also advance the methodological approach on how to estimate bank efficiency. We extend the current methodology introduced by Barros et al (2012) by introducing allocative efficiency and cost efficiency. We also open the black-box on how efficiency and productivity are measured.

In so doing, we analyse, in a unique way, how the individual inputs and outputs affect overall bank efficiency and Total Factor Productivity (TFP) change. This type of examination is key for regulators and banks. It reveals and clearly identifies the fundamental managerial problems at the core of banks and the banking system. So far, a few studies have focused on these important issues, e.g. Barros et al. (2012) and Assaf et al. (2013). Our findings may guide regulators and bank managers in adopting measures that would re-establish a well-functioning banking system in the analysed countries.

The contributions of this study are listed as follows: First, we investigate the link between bank allocative and technical efficiency. Second, our approach enables us to measure the contribution effect on TFP of each inputs. Crucially, the disaggregation of technical efficiency into individual inputs is an addition to contemporary research on bank performance. Third, we test for convergence in productivity growth as well as in the individual bank inputs of the EU28 banks to assess the integration process within the EU28 banking sector. We employ the dynamic Phillips and Sul (2007) panel convergence model which allows for individual heterogeneity while testing for a common growth component. Fourth, the empirical analysis is new in the context of bank efficiency and productivity changes together with convergence in new EU countries. The analysis is particularly relevant given the ongoing consolidation process in EU countries. Accordingly, we investigate the period 2005 to 2014.

The paper is structured as follows: Section 2 provides an overview of European banking literature. Section 3 discusses the methodology and Section 4 presents the empirical results. Finally, Section 5 concludes.

2. Background

2.1. An Overview: European Banking System and the Global Financial Crisis

In the last twenty years, the European banking market has undergone extensive regulatory changes, consolidation through mergers and acquisitions (M&As) and important technological changes that have considerably changed the banking industry. The implementation of the First Banking Coordination Directive in 1977 followed by the EU White Paper in 1985 and the Second Banking Coordination Directive of 1988 provided a cornerstone for the establishment of the Single Market for Financial Services in 1993. The Cecchini Report (1998), which analysed the cost-benefit analysis of a single financial market, argued that a single financial market reduces the costs of financial intermediation, enables more efficient allocation of capital, better access to markets, instrument and services and higher efficiency of the financial institutions and markets. The benefit of a single market was seen, above all, as an increase in competition that will lower the prices of financial services.

Undoubtedly, the European banking markets has, since, been significantly reshaped and the degree of harmonisation has improved compared to the pre-1993 level. Berger (2003) argues that the full efficiency effect of a single market for financial services in Europe would require an intensive wave of mergers and acquisitions of financial institutions across the countries. However, he reports that there have been a rather limited number of M&As among the EU financial institutions. Furthermore, Berger (2003) shows that universal banking in particular, can contribute to scope efficiency and cost improvements. Goddard et al (2007) argue that the integration of the banking sector has not been achieved yet. The main obstacles of the full integration are national economic conditions, differences in legal and fiscal system, and cultural differences, among others. Barros et al (2007) support this view in their study by showing that country-level characteristics (location and tradition), firm-level features (bank ownership, balance sheet structure and size) still matter. They also argue that smaller sized banks with higher loan intensity and foreign banks from countries with common low traditions have a higher chance of best performance. Other studies shows that the process of integration has advanced more in wholesale rather than in retail banking, see, for example, Cabral et al. (2002), Barros et al. (2005).

The most recent global financial crisis has been, to some extent, a test of the degree of financial integration across the EU countries. With the benefit of hindsight, it is now evident that the financial crisis has seriously jeopardised the process of financial integration. As stated by the ECB (2012), financial integration affects financial stability through a variety of channels and can become a conduit transmitting financial shocks and contagion during crisis time. Empirical analysis, not surprisingly, finds strong evidence that bank balance-sheet contagion has indeed been amplified by the exposure of borrowing from cross-border banks (ECB, 2012). To our knowledge, there are no empirical studies that investigate the impact of the current global financial crisis on bank efficiency across all EU28 banks[1].

The cost of the financial crisis in terms of aid provided by EU states to stabilise the EU banking during 2008 and 2012 amounted to EUR 1.5 trillion, a sum equivalent to 12.3% of EU 2012 GDP (European Commission, 2014). The crisis has disclosed the bottlenecks of the integration process. The main weakness of the integration process has been a weak and not fully implemented integrated framework for bank supervision and regulation. This is evident

[1] Matousek et al (2014) analyse the impact of the global financial crisis on EU15's bank efficiency.

from the systemic crisis we have witnessed across the individual EU countries. Furthermore, the extent of the crisis has spread across the EU countries through the balance sheets of financial institutions. As a result, a number of banks have been forced to sell external assets or been required to close their exposure with domestic and/or overseas institutions. Such activities then spread from one bank to another regardless of the geographical frontier.

Tsionas et al. (2015) discuss the cost of restructuring the banking sector in EU. For example, the UK's estimated package should reach US $1.1 trillion in order to restore confidence in the banking system. In Denmark, 13 of the country's 140 banks were bailed out by the central bank or acquired by their competitors. The expected volume of the rescue package is estimated to be EUR 593.9 billion. EU governments approved about EUR 311.4bn for capital injections, EUR 2.92tr for bank liability guarantees, EUR 33bn for relief of impaired assets and EUR 505.6bn for liquidity and bank funding support, a total of EUR 3.77tr.

It is evident that international financial integration increases economic efficiency and growth. However, it may also increase the probability of a systemic banking crisis by transmitting international shocks via bank balance sheets. As already mentioned above, our analysis has important policy making implications. In particular, it should disclose the weakest links in the banking integration process in EU 28countries as well as the contagion channels that undermine bank performance.

2.2. Literature Review

The enlargement of the European Union to 28 member countries has been a significant step in the history of the European Union and the ramifications in terms of the integration process are profound. In theory, a single market in banking across the 28 member states should enable greater consumer choice and boost competition and banking efficiency. Indeed, if a homogenous banking market and competition do lead to further integration, then the impact would be felt on the cost structures and performance of banks (i.e. banking efficiency). As noted by Kasman et al. (2010), the new EU member countries embarked on large-scale privatisation programmes in the mid-1990s in order to boost banking competition and efficiency. As a result, bank consolidation among the Central and Eastern European (CEE) countries peaked in the 2000s and the countries' banking systems are now more viable and efficient (Kasman et al, 2010). Hence a higher level of competition and the presence of an integrated market should translate into convergence in banking efficiency.

There are several studies that investigate the process of European banking integration by using banking efficiency as an indicator for integration (Goddard et al. 2007; Brissimis et al. 2010, Fiordelisi et al. 2011; Weill 2009, Casu and Molyneux 2003; Casu and Girardone 2010.). All these studies, however, focus on the performance of EU15's banks prior to the financial crisis. For instance, Casu and Molyneux (2003) investigate whether productive efficiency in European banking for the period 1993 and 1997 has converted to a common European frontier. Their results point to an improvement in the average efficiency scores, but the efficiency gap between the countries has widened over this period. They conclude that there is little evidence of convergence.

Weill (2009) applies the beta and sigma convergence test[2] to estimated cost efficiency scores[3] for banks from ten[4] European countries for the period 1994 to 2005. Weill (2009), on the other hand, finds evidence in support of convergence in cost efficiency in the EU banking. Similar results are also found by Casu and Girardone (2010), who apply the same methodology to test for convergence in the EU15's banks during the period 1997 to 2003. The authors find

[2] The β-convergence is drawn from the growth literature and models the "catch-up effects" by regressing the growth rate of a variable on the initial level while σ-convergence looks at the dispersion of the cross-section. Convergence is evident is the dispersion decreases over time. See Rughoo and Sarantis (2012) for a comparison of this methodology with the Phillips and Sul method.

[3] Estimated through the stochastic frontier approach

[4] Austria, Belgium, Denmark, France, Germany, Italy, Luxembourg, Portugal, Spain, UK

evidence of bank efficiency convergence and report that the introduction of the single currency has had no effect on the convergence and improvement in efficiency levels in the EU15 countries. The authors find no evidence of group convergence following the onslaught of the global financial crisis.

Kasman et al. (2013), on their part, analyse the convergence of total factor productivity within EU22 countries using the concepts of β-convergence and σ-convergence over the period 1995 to 2006 and find evidence of convergence. To sum up, an overview of the studies on bank efficiency and convergence reveals a significant gap in the literature. There is a clear lack of studies that encompass banks from all the EU28 countries over a recent period of time that includes the financial crisis. We aim to address both lacunas in our paper with an extensive analysis of bank productivity across EU28 banks and the application of robust methodologies.

3. Methodology

This study measures allocative efficiency of input resources and productivity change in the European banking sector. In productivity change estimation, we decompose TFP by contribution effects of each input/output. Additionally, we apply the convergence test to analyse the time trend.

We apply two non-parametric productive efficiency estimation methods, the data envelopment analysis (DEA) and the weighted Russell directional distance model (WRDDM). We apply DEA to evaluate input resource allocative efficiency, and WRDDM to measure TFP and contribution effects of each input/output factor. Both nonparametric approaches propose a measure based on linear programming and have advantages of being relatively easy in treating multiple input and output data. Such a model helps achieve our research objectives which include examining how inputs are allocated in bank production process between the old and new EU countries. We also focus on the impact of the changes of individual input on bank productivity by considering their contribution effect. This is a novel approach, which has not hitherto been applied in recent studies on European bank efficiency (productivity).

3.1 Data envelopment analysis (DEA)

3.1.1. Technical efficiency of input resource use

Many productivity evaluation techniques are based on the frontier efficiency concept originally proposed by Farrell (1957) to evaluate inefficiency by specifying the production frontier with the best performing observations, and measuring the distance of inefficient samples from the frontier. DEA approach was developed by Charnes et al. (1978), wherein nonparametric linear programming techniques are applied.

Let $x \in \Re_+^L, y \in \Re_+^M$ be vectors of inputs and output, respectively, and then define the production technology as:

$$P(x) = \{y: x\ can\ produce\ y\} \tag{1}$$

DEA can compute technical efficiency (TE) of input resource use for bank *k* by solving the following optimization problem:

$$TE_k = Minimize\ \theta_k, \tag{2}$$

$$\text{s.t.} \quad \sum_{i=1}^{N} \lambda_i x_i^l \leq \theta_k x_k^l \qquad l = 1, \cdots, L \tag{3}$$

$$\sum_{i=1}^{N} \lambda_i y_i^m \geq y_k^m \qquad m = 1, \cdots, M \tag{4}$$

$$\lambda_i \geq 0 \qquad i = 1, \cdots, N \tag{5}$$

where *l* and *m* represent types of input and output, respectively. *x* is an input matrix with dimensions $L \times N$ and *y* is a output matrix with dimensions $M \times N$. θ_k is the technical efficiency score of the bank *k* which is defined from zero to one, and $\theta_k = 1$ signifies a bank is efficient.

λ_i is the weight variable. To estimate the technical efficiency score of all banks, the model needs to be applied independently to each of the *N* banks.

In general, the DEA model commonly assumes either constant return to scale (CRS) or variable return to scale (VRS). Equation (2) to (5) represents DEA model under CRS assumption. Ramanathan (2003) explains that VRS assumption takes into account the variation of efficiency with respect to the scale of operation, and hence measures pure technical efficiency. On the other hand, CRS assumption can be made to evaluate efficiency comprising pure technical efficiency and scale efficiency. DEA model under VRS assumption can be estimated by applying equation (2) to (5) and the following equation (6).

$$\sum_{i=1}^{N} \lambda_i = 1 \tag{6}$$

By using productive efficiency score estimated by DEA under CRS and VRS assumption, scale efficiency score can be estimated. Scale efficiency is defined as following equation.

$$\text{Scale efficiency} = TE_{CRS} / TE_{VRS} \tag{7}$$

According to Ramanathan (2003), scale efficiency indicates how each bank scale's is close to the most productive scale size (MPSS) which enjoys the maximum possible economy of scale. Scale efficiency equal to one signals that the bank is identified as at the MPSS.

3.1.2. Cost and allocative efficiency of input resource use

In the previous Section, technical efficiency is defined by each input and each output ratio. However, the decision-makers of banks focus on total input cost efficiency to evaluate their financial performance, especially the balance of the input resource. In this case, an objective efficiency score is needed to consider the balance of multiple input resources.

As stated by Coelli et al. (2002), cost efficiency and allocative efficiency can be estimated by DEA.[5] The cost efficiency evaluates how much total input costs can be decreased without decreasing output. To estimate cost efficiency, the following cost minimisation program is calculated. Cost minimisation program of bank k can be described as follows.

$$Minimise \ \sum_{l=1}^{L}\{p_k^l x_k^{*l}\} \quad (8)$$

$$\text{s.t.} \quad \sum_{i=1}^{N}\lambda_i x_i^l \le x_k^{*l} \qquad l = 1,\cdots,L \quad (9)$$

$$\sum_{i=1}^{N}\lambda_i y_i^m \ge y_k^m \qquad m = 1,\cdots,M \quad (10)$$

$$\lambda_i \ge 0 \qquad i = 1,\cdots,N \quad (11)$$

where p^l is an input price variable which is given and fixed. Input price can be different among type of input variables (l). x_k^{*l} is optimal input amount to minimize total input cost. The score of x_k^{*l} is equal to or less than x_k^l. Cost efficiency (CE) of bank k can be defined as equation (12) by using the result from the cost minimization program. CE is calculated as minimized total input cost divided by the actual total input cost.

$$CE = \sum_{l=1}^{L} p_k^l x_k^{*l} \Big/ \sum_{l=1}^{L} p_k^l x_k^l \quad (12)$$

By using TE and CE, we can estimate allocative efficiency (AE). Allocative efficiency evaluates the allocation of input resources and is described by equations (13) and (14). The score of AE is defined from zero to one, and AE equal to one signifies that the input resource

[5] Cost efficiency can be estimated by both DEA and WRDDM. However, theoretical background of allocative efficiency estimation as CE/TE is constructed in DEA model but not WRDDM. On the other hands, contribution effect to TFP change can be estimated by WRDDM but not DEA. To discuss both allocative efficiency and contribution effect of input factors to TFP change, we apply two linear programing methods which are DEA and WRDDM.

allocation is efficient. AE<1 means that the input resource allocation is inefficient. AE can be estimated under CRS and VRS assumption as follows.

$$AE_{CRS} = CE_{CRS} / TE_{CRS} \tag{13}$$

$$AE_{VRS} = CE_{VRS} / TE_{VRS} \tag{14}$$

3.2 Weighted Russell Directional Distance Model (WRDDM)

WRDDM is developed by Chen et al. (2015) and Barros et al. (2012). Generally, the production frontier analysis evaluates productive inefficiency score by measuring the distance between the production frontier line and each banking firm. In WRDDM estimation, weighted inefficiency score $\vec{D}(x_k, y_k|g)$ can be estimated by using the distance measured by multiple viewpoints which are inefficiency of output (α_k^m) and inefficiency of input (β_k^l). Equation (15) to (18) represent the WRDDM for the inefficiency score of bank *k*:

$$\vec{D}(x_k, y_k|g) = maxmize\left(w_y \sum_{m=1}^{M} \omega_y^m \alpha_k^m + w_x \sum_{l=1}^{L} \omega_x^l \beta_k^l\right) \tag{15}$$

Subject to

$$\sum_{i=1}^{N} \lambda_i y_i^m \geq y_k^m + \alpha_k^m g_{y_k^m} \qquad m = 1, \cdots, M \tag{16}$$

$$\sum_{i=1}^{N} \lambda_i x_i^l \leq x_k^l - \beta_k^l g_{x_k^l} \qquad l = 1, \cdots, L \tag{17}$$

$$\lambda_i \geq 0 \qquad i = 1, \cdots, N \tag{18}$$

$\vec{D}(x_k, y_k|g)$ represents the aggregated inefficiency score of bank k and defined from zero to one. $\vec{D}(x_k, y_k|g) = 0$ means that bank k is efficient and a larger score shows more inefficient performance. λ_i is the intensity variable to determine the shape of the frontier line. According to Chen et al. (2015),WRDDM can evaluate the inefficiency of each input and output factors while considering the characteristics of each factor.

The w_y and w_x are given priorities associated with the output and input variables. Because the objective of this research is to clarify the efficiency of individual input factor, we apply the input-oriented WRDDM model with setting (w_y=0, w_x=1). Additionally, the ω_y^m and ω_x^l are given priorities associated with the data variables among each of the outputs and the inputs. According to Chen et al. (2015), equal data weight setting has the advantage to understand the inefficiency score estimated WRDDM. This is because equal weights allow inefficiency scores not to be affected by the number of data variables. Therefore, we set the priority weights as equal (i.e. ω_l^x=1/L).

Additionally, $g_{x_k^l}$ is a directional vector which defines the way of distance measure from each bank to the production frontier line. We choose the proportional directional vector which has the advantage of calculating the productivity change indicator. By applying the proportional directional vector as $g_{x_k^l} = x_k^l$, the WRDDM is shown as follows:

$$\vec{D}(x_k, y_k|g) = maximize\ \left(\frac{1}{L}\sum_{l=1}^{L}\beta_k^l\right) \tag{19}$$

Subject to

$$\sum_{i=1}^{N}\lambda_i y_i^m \geq y_k^m \qquad m = 1, \cdots, M \tag{20}$$

$$\sum_{i=1}^{N}\lambda_i x_i^l \leq x_k^l(1-\beta_k^l) \qquad l = 1, \cdots, L \tag{21}$$

$$\lambda_i \geq 0 \qquad i = 1, \cdots, N \tag{22}$$

The proportional directional vector, as set above, measures the distance from each bank to the frontier line by focusing on how much each bank can decrease its input factors. The advantage of the proportional directional vector is that it yields a straightforward interpretation of the inefficiency score. The inefficiency score illustrates the percentage by which each bank can decrease their input in relation to the frontier line. Therefore, a proportional directional vector allows the inefficiency score to be independent from the unit of data. Additionally, a proportional directional vector has also the advantage of deciphering TFP change and the contribution effect of each variables. Notably, the contribution effect estimated by proportional directional vector directly represents the percentage of production inefficiency change.

Similar to the DEA model, WRDDM can be set up under the CRS and VRS assumption. Equation (19) to (22) display WRDDM under CRS assumption. WRDDM under VRS assumption can be estimated by applying equation (19) to (22) and the restriction for λ expressed in equation (6).

According to Fujii et.al. (2014) and Fujii et al. (2015), total factor productivity (TFP) change and the contribution effect of each input/output factor into TFP change can be estimated by using the inefficiency score of the WRDDM. This study employs the Luenberger Productivity Indicator as a TFP measure because the Luenberger Productivity Indicator has the advantage over productivity change estimation due to the additive distance function model compared to the Malmquist productivity index (Balk et al., 2008).

To better understand the structure of TFP change, Färe et al. (1994) developed the decomposition of TFP into technical change (TECHCH) and efficiency change (EFFCH). TFP estimated by WRDDM and Luenberger productivity indicator is represented as follows:

$$\mathrm{TFP}_{\mathrm{t}}^{\mathrm{t+1}} = \frac{1}{2}\left\{\vec{\mathrm{D}}^{\mathrm{t+1}}(x_k^t, y_k^t) - \vec{\mathrm{D}}^{\mathrm{t+1}}(x_k^{t+1}, y_k^{t+1}) + \vec{\mathrm{D}}^{\mathrm{t}}(x_k^t, y_k^t) - \vec{\mathrm{D}}^{\mathrm{t}}(x_k^{t+1}, y_k^{t+1})\right\} \tag{23}$$

$$\mathrm{TECHCH}_{\mathrm{t}}^{\mathrm{t+1}} = \frac{1}{2}\left\{\vec{\mathrm{D}}^{\mathrm{t+1}}(x_k^t, y_k^t) + \vec{\mathrm{D}}^{\mathrm{t+1}}(x_k^{t+1}, y_k^{t+1}) - \vec{\mathrm{D}}^{\mathrm{t}}(x_k^t, y_k^t) - \vec{\mathrm{D}}^{\mathrm{t}}(x_k^{t+1}, y_k^{t+1})\right\} \tag{24}$$

$$\mathrm{EFFCH}_{\mathrm{t}}^{\mathrm{t+1}} = \vec{\mathrm{D}}^{\mathrm{t}}(x_k^t, y_k^t) - \vec{\mathrm{D}}^{\mathrm{t+1}}(x_k^{t+1}, y_k^{t+1}) \tag{25}$$

$$\mathrm{TFP}_{\mathrm{t}}^{\mathrm{t+1}} = \mathrm{TECHCH}_{\mathrm{t}}^{\mathrm{t+1}} + \mathrm{EFFCH}_{\mathrm{t}}^{\mathrm{t+1}} \tag{26}$$

Where x^t shows the input for year t, x^{t+1} represents the input for year t+1, y^t is the output for year t, and y^{t+1} is the output for year t+1. $\vec{\mathrm{D}}^{\mathrm{t}}(x_k^t, y_k^t)$is the productive inefficiency in year t evaluated by using production frontier line in year t. Similarly, $\vec{\mathrm{D}}^{\mathrm{t+1}}(x_k^t, y_k^t)$ is the inefficiency of year t evaluated by using production frontier line in year t+1. The TFP can be decomposed into TECHCH and EFFCH as shown in equation (26).

By using input oriented WRDDM, we have a further decomposition of TFP. From Fujii et al. (2014) and Fujii et al. (2015), TFP can be decomposed into each variables' contribution effect as follows.

$$\mathrm{TFP}_{\mathrm{t}}^{\mathrm{t+1}} = \sum_l \mathrm{TFP}_{\mathrm{t},x_l}^{\mathrm{t+1}} \tag{27}$$

$$\mathrm{TECHCH}_{\mathrm{t}}^{\mathrm{t+1}} = \sum_l \mathrm{TECHCH}_{\mathrm{t},x_l}^{\mathrm{t+1}} \tag{28}$$

$$\mathrm{EFFCH}_{\mathrm{t}}^{\mathrm{t+1}} = \sum_l \mathrm{EFFCH}_{\mathrm{t},x_l}^{\mathrm{t+1}} \tag{29}$$

$\mathrm{TFP}_{\mathrm{t},x_l}^{\mathrm{t+1}}$ shows the contribution effect of inputs factor l for TFP change. So by considering the contribution effect indicator, we can comprehend the reasons why TFP has changed by analysing each input's performance change.

3.3 Convergence in productivity change

We employ the dynamic panel method, Phillips and Sul (2007) convergence methodology, to test for convergence in the estimated total factor productivity, efficiency change and technical change as well as in the inefficiency of 3 individual inputs, namely personnel expenses, total fixed assets and total deposits. We consider all the banks in our sample of EU28 banks as well as, separately, banks from the EU15 countries and from the new EU countries respectively. This model is a regression-based panel convergence methodology which analyses co-movements and convergence in the context of individual heterogeneity and the evolution of this heterogeneity across different groups and over time. So this approach has the benefit of testing for convergence within a heterogeneous setup that allows for a wide range of possible time paths.

The Phillips and Sul approach addresses the concept of transitional heterogeneity by working with the relative transition coefficients, h_{it}, which represents the share of each bank's productivity indicator or inefficiency score, y_{it}, relative to the cross-section average productivity indicator or inefficiency score in the panel ($h_{it} = logy_{it}/\overline{logy_t}$). Using the relative transition coefficients, Phillips and Sul (2007) propose a regression based 'logt' test[6] as follows:

$$\text{Log}\,\frac{H_1}{H_t} - 2\log(logt) = a + \gamma\log t + u_t, \text{ for t} = T_0, \ldots\ldots, T \qquad (30)$$

Where $H_t = N^{-1}\sum_{i=1}^{N}(h_{it} - 1)^2$ and γ measures the speed and magnitude of convergence. The test statistic is normally distributed and using the 5% significance level, the null hypothesis of convergence is rejected if the test statistic is < -1.65. Additionally, If $\gamma \geq 2$, convergence in the level productivity indicators or inefficiency scores is present whereas if $2 > \gamma \geq 0$, then the speed of convergence relates to conditional convergence, i.e. convergence in the rate of change of the indicators. The findings from the log*t* test enables us to determine whether convergence within the panel is present or not. In addition, the relative transition coefficients

6 See Phillips and Sul (2007, 2009) for a detailed explanation and Rughoo and Sarantis (2014) and Matousek et al. (2014), for an application.

can be plotted for a visual depiction of the convergent or non- convergent behaviour of the productivity indicators and the inefficiency scores for individual inputs.

4. Data and Empirical results

4.1. Data

This study uses each bank's financial data from BankScope. To select the input and output variable combination, we apply the intermediation approach to set the bank performance modelling. Generally, there are two approaches to model bank performance; the intermediate approach and the production approach. The main difference lies in the treatment of purchased funds. The former approach evaluates bank performance by focusing on both physical input and purchased funds. Meanwhile, the production approach focuses only on physical inputs but not so much on purchased funds.

There have been extensive discussions on the different approaches of how to measure bank efficiency. Based on a large number of studies it is accepted that the intermediation approach has the upper hand in evaluating bank performance. The production approach is, on its part, appropriate in evaluating the financial performance of bank branches, for example see Berger and Humphrey (1997). Given that the objective of this research is to evaluate the financial performance of entire banks, we apply the intermediation approach to select the combination of input and output variables. The adoption of this approach is further supported by a number of empirical studies (See Sealey and Lindley, 1977, Fujii et al. 2014, Matousek et al, 2015).

The selection of inputs and outputs follows the recent empirical studies on bank efficiency (See Matousek et al (2014), Assaf et al (2013), Shen et al (2009)). Thus, to estimate TE and CE using the DEA, we employ as input variables: total number of employees, fixed assets, and deposits. The following three output variables are used in our model: customer loans, other earning assets, and non-interest income, defined as net fees and commission and other operating income.

In addition to the above data variables, the following three input price data are used to estimate CE: The price of labour is calculated as personnel expenses divided by the total number of employees. Price of funds is calculated as total interest expenses on deposits divided by total deposits. We use a proxy variable for price of capital which is calculated as the ratio of other operating expenses to total fixed assets. We obtain this data from BankScope database. Finally, we define total costs as the sum of interest expenses, personnel expenses and other operating expenses.

In WRDDM estimation, following Matousek et al (2014), we apply the following three input variables: personnel expenses, fixed assets, and deposits. The three output variables are customer loans, other earning assets, and non-interest income. The data variable combination for each model are given in Table 1.

The dataset covers 927 banks for the period 2005 to 2014, and all financial variables are deflated to 2010 prices. Descriptive statistics are provided in Table 2. To deepen our analysis, the banks are further divided into two groups, those located in the 'old' EU15 countries and the rest based in the new EU countries.

<Insert Tables 1 & 2>

4.2. Bank efficiency analysis

We report technical efficiency (TE), cost efficiency (CE), and allocative efficiency (AE) under the assumption of CRS and VRS in Table 3. The scores show the country and year average efficiency indicator from 2005 to 2014. All three efficiency indicator are defined from zero to one, and a larger score indicates better performance.

From Table 3, it is noted that the highest TE scores are achieved on average in Ireland, Sweden, and Belgium which are part of EU15. The lowest TE scores are observed in Romania, Latvia, and Bulgaria. We find similar trends for the TE scores under both CRS and VRS assumptions. Additionally, high scale efficiency scores are observed in Sweden, Denmark, and Germany. Sweden and Denmark achieve high efficiency score in both TE and scale efficiency. These results imply that banks in Sweden and Denmark enjoy the maximum possible economy of scale. On the other hands, Banks in Germany achieve high scale efficiency while technical efficiency is not high. These results indicate that even though the size of the inputs and outputs in German banks is appropriate, the inputs are not being used as efficiently.

We also report CE and AE in Table 3. The CE scores are very volatile across the countries and the banks from the new EU countries bear the lowest efficiency levels. Surprisingly, low CE scores are also observable for banks from Italy and Luxembourg. Notably, for Italian banks, as reported in Table 3, low CE and AE scores are noted while TE is at an average level. This implies that Italy's banks' AE is low due to low CE performance. Therefore, based on these results, we can argue that efforts to increase CE performance may prove to be more effective in boosting AE for banks in Italy.

We also provide a comparison between bank efficiency levels in old and new EU countries in Table 3 and it is evident that new EU banks are on the average less efficient than banks from old EU countries. We examine the Kruskal-Wallis test to confirm the significant differences between the efficiency levels for new and old EU countries. The results reject the null hypothesis of equal bank efficiency among them. From Figure 1 and Table 3, it is evident that country group average score for TE and CE in new EU countries are still below bank efficiency scores in old EU countries under both CRS and VRS assumption. These results support previous empirical findings e.g., Kasman et al. (2013), Casu and Girardone (2010). These findings are interesting since the majority of banks in new EU countries are mostly owned by foreign banks. A closer look at Table 3, however, reveals that some countries from new EU such as Romania and Bulgaria are well below the average efficiency scores. Table 4 then provides an even more detailed analysis that lists annual efficiency scores.

<Insert Figure 1>

<Insert Table 3>

Next, in Table 4 we provide bank efficiency scores over the observed time period. Interestingly, it is noted that TE fell in 2008 for the banks from EU15 but not for banks from the new EU countries. One possible interpretation of these results could come from the structure of loan which differs between old EU and new EU countries. Our results show that that the global financial crisis has had a negative impact on bank efficiency, and mainly on banks from the old EU. The majority of 'old' EU countries faced an unprecedented bailout and capital crunch that significantly deteriorated bank business activities. On the other hand, banking systems in most 'new' EU countries survived this period without any notable difficulties. One of the main reasons is that banks in 'new' EU countries had no or only marginal exposure to the structured financial products, in particular Collateral Debt Obligations and/or Credit Default Swaps that originated in USA.

Additionally, Table 4 reports that TE and CE decreased rapidly from 2012 to 2013 in both 'new' and 'old' EU countries. One likely interpretation of these results comes from the heightened financial risk from the Greek economic crisis.

<Insert Table 4>

Incidentally, based on the DEA estimation, we cannot identify which input factor actually worsened in both 'old' and 'new' EU countries. Therefore, we expand our analysis by using WRDDM to identify the specific input factor which led to a decreased bank performance.

4.3. Productivity change and contribution effect of inputs

Our model, as we have already indicated, enables us to analyse the effect of the utilised inputs on bank performance and productivity. Table 5 provides the inefficiency scores of the 3 bank inputs we have employed. It is evident that deposits are optimally managed by banks with markedly low inefficiencies compared with personnel expenses and fixed assets. The average inefficiency level of all banks for personnel expenses and fixed assets achieved more than 0.7 under both CRS and VRS assumption. This result implies that 70% of personnel expenses and fixed assets can be saved without decreasing outputs to achieve an efficient bank performance. Additionally we note that, not surprisingly, between the period 2007-2009, aggregate inefficiency scores increased for all the EU28 banks. Subsequently the aggregate inefficiency scores dipped but rose again from 2012 to 2013 due to a rapid increase in total deposits. This result reveals that the efficiency gap between efficient bank and inefficient bank became larger. These findings reflect the changes in bank behaviour during and after the financial crisis. The results suggests that bank liquidity concerns caused by the deteriorating quality of assets forced banks to reduce or completely stop their lending activities. . Indeed, as reported by the OECD (2012), with banks focusing on reducing their pre-crisis leverage levels and in anticipation of stricter regulatory capital requirements, bank lending has been lower.

<Insert Table 5>

We also report the disaggregated inefficiency scores separately for the banks from the 'old' and 'new' EU countries in Table 5. We note that the input inefficiency scores in 2005 are largely different between banks in EU15 and those in new EU countries, especially for the inefficiency scores for total deposits. However, the gap narrows down in 2013 and 2014. This is a key finding that demonstrate a process of catching up of banks from new EU countries with their counterparts in EU15.

We analyse if the estimated inefficiency scores are statistically different among our two groups. The last row of Table 5 shows the p-value of Kruskal-Wallis test. The results reject the null hypothesis of equal inefficiency across these two groups of banks in many cases but the pattern is diverse. The inefficiency of fixed assets under CRS model and the inefficiency of personnel expenses under VRS model are found to be significantly different between the old and new EU countries. The interesting point is that the average inefficiency of fixed assets in old EU countries is larger than the new EU countries average in 2008, 2010, and 2011 and are statistically significant. One interpretation of this result is that fixed assets' efficiency usage decreased due to the global financial crisis and this rendered the process of effective investments by large scale bank much more difficult. Given that the CRS assumption includes both pure technical efficiency and scale efficiency of production, large banks with excess capital in old EU countries experienced higher inefficiency scores in the use of their fixed assets in the aftermath of the financial crisis.

Next, we discuss the productivity changes and contribution effect of inputs factors. TFP changes are analysed separately for old and new EU countries. Table 6 and 7 provide a description of not only TFP changes but also reports the input factors that contribute to TFP under CRS and VRS assumption, respectively. As one may expect old EU countries show negative values for the period 2007-2008 in both CRS and VRS assumption. This can be primarily explained through the negative impact of the global financial crisis. Interestingly, we note that this drop in TFP for banks from old EU countries results from a fall in the contribution effect of personnel expenses and total deposits during the crisis period. Post-2009, under both the CRS and VRS assumption, we note a marked increase in the positive contribution effect of total fixed assets and total deposits whilst the contribution effect of personnel expenses is very limited. Meanwhile, TFP scores in new EU countries show a gradual and consistent increase between 2007 to 2014. The contribution effect for all 3 inputs are positive and notably higher for total deposits. These overall results imply that the global financial crisis had a bigger negative impact on banks in old EU countries. These trends are consistent with the previous discussion wherein banks in new EU countries are seen to go through a catching up phase with the efficient banks.

Next, we decompose TFP into Efficiency Change (EFFCH) and Technical Change (TECHCH). EFFCH measures changes in the position of a bank relative the frontier and TECHCH shows shifts in the production frontier. Fujii et al. (2014) provide a detailed discussion about the decomposition process. As for banks from old EU countries we observe that both components of TFP have negative values over the analysed period. In particular, all the values for efficiency change are negative throughout the whole period under both the CRS and VRS assumption for banks from old EU countries. As for technical change, the negative contribution effect mostly stems from personnel expenses. On the other hand, new EU countries show positive numbers that indicate positive technical change and efficiency change. In particular, EFFCH of banks from new EU countries under VRS assumption is clearly on a different trend compared to their counterparts in EU15. Once more, the contrasting impact of the global financial crisis on banks from the old EU countries on one hand and banks from the new EU countries is evident.

<Insert Tables 6 and 7>

4.4. Convergence

In the following Section, we further investigate whether we can identify a common trend across EU countries in terms of productivity as well as in individual bank inputs. The convergence results on productivity and on the inefficiency scores for the individual inputs turn out to be quite revealing (see Table 8). For the whole sample of 927 banks from the EU28 countries, we cannot detect any convergence for overall TFP at the 5% significance level. However, convergence is present for all EU28 banks in terms of both efficiency change ($\boldsymbol{\gamma}$ =1.570) and technical change ($\boldsymbol{\gamma}$ =3.813). Given that $2 > \gamma \geq 0$ for efficiency change, the type of convergence here relates to conditional convergence, i.e. convergence in the rate of change. As for technical change, with $\gamma \geq 2$, we note that convergence is in the level values. For the sample of banks from the old EU countries, we find no convergence for TFP ($\gamma = -2.955$) and none for efficiency change ($\gamma =$-1.150). However, strong convergence in levels is identified for technical change ($\gamma = 4.410$). For the banks from the new EU countries, the trend is very similar to what we have noted for banks from the old EU. There is no convergence in TFP ($\boldsymbol{\gamma}$ =-11.023) nor in efficiency change ($\boldsymbol{\gamma}$ =-2.596). However, conditional convergence is present for technical change ($\boldsymbol{\gamma}$ =1.905). The results clearly suggest that over the period 2005-2014, convergence in EU 28 in technical change, i.e., where banks are experiencing a shift in their production frontier is being predominantly driven by banks from the old EU countries. Overall, this is a significant finding as firstly, it would signal that the sample of banks from EU28 are altogether integrating with respect to technical change but also secondly, that the banks from the new EU countries are catching up with their counterparts from the old EU countries in terms of technical change. Our results somewhat tally with those of Kasman et al

(2013)[7] who find evidence of convergence among the 22 EU member countries plus 3 candidate countries over an earlier period; 1995-2006.

The convergence results on the inefficiency scores (see Table 8) for the individual inputs show that across the EU28 banks, there is no evidence of convergence for personnel expenses (x1) (γ =-1.125) and total fixed assets (x2) (γ =-1.054) while weak convergence is detected for total deposits (x3) (γ =-0.363). When we split the sample into banks from the old EU countries and those from the new EU countries, the results are consistently similar. There is once more no convergence detected for personnel expenses and total fixed assets inefficiency scores while slow convergence is once more detected for total deposits (x3) (γ =-0.362, γ =-0.360). These results tie in with the findings discussed in Section 4.3 wherein it is argued that that deposits are optimally managed by banks with low inefficiencies compared with personnel expenses and fixed assets. So overall, we can conclude that with respect to the banks' individual inputs' inefficiency scores, the picture of one of strong heterogeneity.

<Insert Table 8>

We also plot the transition paths, for 1) TFP, efficiency change and technical change and 2) the individual inputs i.e. x1, x2, and x3 for the banks from the EU15 and new EU countries. Each transition path illustrates the behaviour of the transition coefficients vis-à-vis the panel average for each variable over the time period 2005-2014. Convergence is detected if the transition paths move asymptotically towards one. This procedure is insightful as it provides a

[7] Kasman et al (2013) apply a different convergence methodology (the beta and sigma convergence method) and do not split their sample between the old and new EU member countries.

visual image of the convergence or divergence process underway and also allows inferences to be drawn with regards to each variable's behaviour.

Figure 2 illustrates the paths of the transition parameters for TFP, efficiency change and technical change. The striking observation is the clear divergence observed in the paths for TFP, efficiency change and technical change over the periods 2007 to 2010 for both EU15 and new EU countries. We attribute this heterogeneous behaviour to the severe impact of the global financial crisis which started in 2007. We can also observe that the paths for technical change exhibit strong convergence behaviour as they move close to the cross-section average, from 2011 and onwards. This behaviour underpins the log*t* results.

<Insert Figure 2>

Figure 3 illustrates the paths for the inefficiency scores for the individual inputs. The noticeable observation is that the paths for both the EU15 and new EU countries tend to show fairly heterogeneous behaviour from the start and throughout. These results tally with the findings from the group convergence findings. Additionally, we can observe heightened diversity around the financial crisis period and once again, the impact of the crisis seems evident.

<Insert Figure 3>

5. Conclusions

This paper conducts a thorough empirical investigation of the convergence process in European retail banking sector by applying an innovative Weighted Russell Directional Distance Model. The analysis covers bank performance in the EU 28 countries for the period 2005 to 2014. The key contributions of this paper include the construction of three types of banking efficiency scores for all members of the European Union as well as the estimation of the disaggregated inefficiency scores for 3 bank inputs and finally the application of the Phillips and Sul (2007) convergence methodology, which detects the presence of convergence and provides an estimate of the speed of convergence.

The paper reveals some important information that have policy implication for managers and regulators following the financial crisis. We demonstrate that bank efficiency has been undermined by the financial crisis in banks notably from old EU countries. We argue that bank efficiency and productivity in EU countries diverge across the banking sector. We further identify signs of an improvement in terms of efficiency and productivity in 2010. Nevertheless, we cannot verify if this is a trend. One would expect that the occurrence of the crisis and subsequent government interventions do distort the business environment in which banks operate.

We extend the literature on European banking integration by testing for convergence in productivity and efficiency of European banks. We further our analysis and investigate the convergence in banks' individual output. The use of the Phillips and Sul (2007) regression-based test is a major contribution of this paper as this methodology not only detects the presence and degree of integration but also provides an estimate of the speed of convergence. It also provides a visual depiction of the integration process.

Overall, the convergence results point to no group convergence in total factor productivity. However we find evidence of convergence in the components of the productivity indicator; i.e. efficiency change and, in particular, in technical change. For the latter, integration is clearly driven by strong convergent behaviour for technical change from the old EU countries' banks. We find that the banks from the old EU countries are converging when analysing shifts in their production frontier while banks from the new EU countries are clearly catching up with their counterparts from the old EU countries. This signifies that continued investment in boosting the components of productivity at bank-level should eventually translate into further integration within the EU28 banking sector. It can further be argued that the detection of convergent behaviour in the components of the productivity indicator should fuel greater competition in the European banking sector, thus tying in with one of the policy objectives of the Single Market. Convergence in the inefficiency scores of individual inputs is almost non-existent during the period 2005-2014. These results are underpinned by the highly divergent behaviour of the transition paths, especially during the crisis years.

Overall, the efficiency, productivity and convergence findings reveal gaping differences in the performance and behaviour of banks across the EU28. These present numerous challenges for policy-makers, regulators and practitioners in the EU. Undoubtedly, the results confirm that the global financial crisis has amplified the divergence process across EU banks. The key question is whether the current trend is only short-term or one that will be very difficult to reverse. There is anecdotal evidence that the performance and systemic stability of the banking sector are deeply embedded within the economic performance of the countries in questions. In particular, some of the 'old' EU countries face a further macroeconomic deterioration that will sooner or later be reflected in the stability and performance of the individual banks and the banking system as a whole. Our results unambiguously show that there are remarkable disparities in terms of bank performance. Thus, we may expect even further deepening of these systemic changes across EU banks. This could also further undermine the overall financial stability.

So far we have witnessed a number of bank closure and intensified M&As activities of well-established banks. We may expect that EU authorities and financial regulators will face a second round of bank bail-outs, capitalisation and consolidation of the banking systems within the individual countries. Indeed, the current poor performance of many banks across the EU countries cannot be reversed without additional financial support. The segment of the small and medium-sized banks is particularly vulnerable and sensitive to macroeconomic conditions.

The global financial crisis has taught us that the depth and consequences of the crisis could not be reversed by having sophisticated regulators. Indeed, Basel II framework failed during the first test. Our results do not also provide any evidence that the calls for strengthening the integration process by setting up pan-European supervisory body is a panacea for resolving poor bank performance and the divergence process. After all, the integration process of the banking sector has been taking place for almost three decades and the results still remain blurred.

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Table 1. Data variable combination for each model

		Input (x)	Input price (p)	Output (y)
DEA model	Technical efficiency (TE)	1. Number of employees 2. Fixed assets 3. Deposits	Not used	1. Customer loans 2. Other earning assets 3. Non-interest income
	Cost efficiency (CE)	1. Number of employees 2. Fixed assets 3. Deposits	1. Price of labour 2. Price of capital 3. Price of funds	1. Customer loans 2. Other earning assets 3. Non-interest income
WRDDM		1. Personal expenses 2. Fixed assets 3. Deposits	Not used	1. Customer loans 2. Other earning assets 3. Non-interest income

Table 2. Data description

Year	Personnel expenses (Million EUR)		Fixed assets (Million EUR)		Deposits (Million EUR)		Customer loans (Million EUR)		Other earning assets (Million EUR)		Total non-interest income (Million EUR)		Number of employees (Persons)		Total cost (Million EUR)	
	Mean	Std.dev	Mean	Std.dev	Mean	Std.dev	Mean	Std.dev	Mean	Std.dev	Mean	Std.dev	Mean	Std.dev	Mean	Std.dev
2005	165	756	176	980	19,514	97,109	10,527	49,106	7,431	48,261	231	1,218	2,893	12,032	932,014	4,119,913
2006	183	883	177	985	21,080	103,421	11,699	54,004	7,319	44,084	277	1,499	3,023	12,591	1,098,859	5,029,354
2007	184	861	179	959	23,235	115,618	13,007	61,240	8,203	51,144	272	1,435	3,252	13,522	1,283,528	5,704,938
2008	175	785	175	985	25,501	134,330	13,465	60,586	9,962	74,850	170	911	3,481	14,971	1,316,231	5,714,076
2009	180	839	186	1,081	23,357	112,549	13,096	58,356	8,126	51,082	233	1,248	3,373	14,639	1,024,906	4,481,500
2010	192	940	182	1,022	24,125	118,437	13,820	63,021	8,857	57,612	243	1,354	3,296	14,691	1,017,236	4,865,360
2011	194	947	162	880	24,577	122,188	13,494	61,434	9,259	61,840	212	1,272	3,292	14,893	1,054,732	5,020,480
2012	189	917	160	883	23,759	116,143	13,064	57,996	9,048	58,257	216	1,181	3,239	14,504	1,021,067	4,831,994
2013	180	886	152	833	21,678	103,182	12,307	53,381	8,133	51,246	214	1,183	3,126	13,932	922,718	4,431,902
2014	180	873	160	980	22,129	107,402	12,401	54,806	8,976	56,872	202	1,045	3,014	13,349	863,385	4,170,052

Table 3. DEA efficiency scores by country

	EU		Technical Efficiency		Cost efficiency		Allocative efficiency	
		TEcrs	TEvrs	Scale efficiency	CEcrs	CEvrs	AEcrs	AEvrs
GERMANY	Old	0.561	0.601	0.939	0.351	0.376	0.622	0.620
UNITED KINGDOM	Old	0.627	0.770	0.833	0.415	0.621	0.645	0.784
FRANCE	Old	0.553	0.643	0.873	0.358	0.461	0.640	0.690
SPAIN	Old	0.671	0.861	0.797	0.426	0.626	0.643	0.717
NETHERLANDS	Old	0.611	0.755	0.815	0.463	0.609	0.743	0.775
ITALY	Old	0.591	0.705	0.850	0.287	0.372	0.486	0.519
SWEDEN	Old	0.742	0.765	0.975	0.446	0.490	0.593	0.627
DENMARK	Old	0.658	0.688	0.963	0.372	0.423	0.535	0.579
BELGIUM	Old	0.713	0.798	0.886	0.511	0.609	0.710	0.750
FINLAND	Old	0.664	0.912	0.733	0.399	0.728	0.615	0.799
AUSTRIA	Old	0.612	0.688	0.902	0.365	0.434	0.586	0.621
IRELAND	Old	0.770	0.946	0.814	0.489	0.606	0.667	0.648
GREECE	Old	0.508	0.744	0.705	0.348	0.480	0.690	0.650
PORTUGAL	Old	0.606	0.766	0.806	0.453	0.573	0.741	0.737
LUXEMBOURG	Old	0.406	0.545	0.730	0.286	0.419	0.653	0.758
CZECH REPUBLIC	New	0.599	0.694	0.878	0.414	0.457	0.683	0.674
CYPRUS	New	0.459	0.602	0.793	0.326	0.387	0.706	0.650
POLAND	New	0.527	0.794	0.672	0.363	0.480	0.687	0.610
HUNGARY	New	0.471	0.729	0.658	0.314	0.437	0.664	0.597
ROMANIA	New	0.323	0.471	0.733	0.207	0.264	0.652	0.571
SLOVENIA	New	0.533	0.624	0.866	0.355	0.385	0.659	0.619
SLOVAKIA	New	0.503	0.625	0.828	0.293	0.316	0.577	0.524
LITHUANIA	New	0.486	0.569	0.871	0.358	0.387	0.719	0.675
MALTA	New	0.565	0.664	0.858	0.360	0.385	0.633	0.585
LATVIA	New	0.367	0.416	0.882	0.226	0.266	0.588	0.628
ESTONIA	New	0.478	0.603	0.838	0.311	0.364	0.645	0.609
CROATIA	New	0.446	0.512	0.896	0.297	0.327	0.665	0.646
BULGARIA	New	0.380	0.442	0.877	0.281	0.300	0.734	0.686
Country group average								
Old EU countries	814	0.584	0.649	0.909	0.362	0.420	0.613	0.635
New EU countries	113	0.463	0.588	0.815	0.310	0.362	0.663	0.623
Prob > |z|		0.000	0.000	0.000	0.000	0.000	0.000	0.039

Note 1: Efficiency score is defined from zero to one and larger score represents better performance.

Note 2:The Kruskal-Wallis test was applied to estimate probability as shown in the last row.

Table 4 Average scores of DEA efficiency score for individual years

		Technical efficiency			Cost efficiency		Allocative efficiency	
	Year	TEcrs	TEvrs	Scale efficiency	CEcrs	CEvrs	AEcrs	AEvrs
All bank (927)	2005	0.642	0.684	0.940	0.406	0.443	0.628	0.640
	2006	0.593	0.651	0.917	0.389	0.431	0.652	0.655
	2007	0.594	0.648	0.923	0.424	0.474	0.712	0.725
	2008	0.569	0.636	0.909	0.424	0.480	0.742	0.749
	2009	0.593	0.659	0.912	0.365	0.427	0.615	0.641
	2010	0.574	0.645	0.904	0.334	0.400	0.582	0.612
	2011	0.563	0.638	0.897	0.330	0.397	0.582	0.609
	2012	0.615	0.679	0.912	0.347	0.400	0.559	0.576
	2013	0.485	0.601	0.832	0.283	0.357	0.580	0.579
	2014	0.464	0.575	0.833	0.251	0.322	0.537	0.546
Old EU (814)	2005	0.666	0.700	0.953	0.420	0.458	0.627	0.646
	2006	0.615	0.666	0.929	0.400	0.445	0.647	0.658
	2007	0.614	0.660	0.938	0.436	0.486	0.706	0.728
	2008	0.585	0.640	0.925	0.434	0.488	0.739	0.754
	2009	0.608	0.665	0.925	0.367	0.429	0.601	0.637
	2010	0.588	0.649	0.918	0.337	0.404	0.569	0.611
	2011	0.575	0.643	0.908	0.332	0.401	0.573	0.608
	2012	0.624	0.684	0.918	0.349	0.403	0.553	0.575
	2013	0.492	0.604	0.840	0.286	0.361	0.577	0.580
	2014	0.473	0.580	0.840	0.255	0.328	0.536	0.548
New EU (113)	2005	0.469	0.568	0.848	0.304	0.336	0.637	0.597
	2006	0.438	0.544	0.827	0.306	0.334	0.693	0.629
	2007	0.443	0.565	0.814	0.334	0.388	0.751	0.700
	2008	0.456	0.608	0.797	0.348	0.425	0.758	0.709
	2009	0.486	0.621	0.817	0.348	0.413	0.717	0.672
	2010	0.473	0.610	0.810	0.320	0.374	0.672	0.620
	2011	0.474	0.602	0.817	0.312	0.369	0.651	0.612
	2012	0.552	0.643	0.869	0.337	0.378	0.603	0.584
	2013	0.431	0.581	0.772	0.266	0.327	0.603	0.572
	2014	0.403	0.541	0.779	0.225	0.279	0.547	0.534

Note: Efficiency score is defined from zero to one and a larger score represents better performance.

Table 5 Disaggregated inefficiency score estimated by WRDDM

	Year	Constant return to scale (CRS)				Variable return to scale (VRS)			
		Aggregate inefficiency	Personnel expenses	Fixed assets	Total deposit	Aggregate inefficiency	Personnel expenses	Fixed assets	Total deposit
All bank (927)	2005	0.601	0.802	0.868	0.132	0.557	0.748	0.805	0.118
	2006	0.635	0.821	0.880	0.205	0.587	0.773	0.825	0.162
	2007	0.629	0.823	0.886	0.179	0.568	0.746	0.806	0.150
	2008	0.637	0.797	0.903	0.210	0.572	0.715	0.817	0.182
	2009	0.652	0.844	0.916	0.196	0.586	0.772	0.825	0.162
	2010	0.646	0.827	0.920	0.191	0.581	0.747	0.827	0.169
	2011	0.662	0.846	0.921	0.218	0.589	0.739	0.837	0.192
	2012	0.638	0.842	0.902	0.172	0.574	0.735	0.828	0.157
	2013	0.685	0.810	0.826	0.420	0.599	0.709	0.774	0.313
	2014	0.698	0.794	0.841	0.458	0.608	0.694	0.790	0.342
Old EU (814)	2005	0.588	0.796	0.864	0.105	0.542	0.735	0.795	0.096
	2006	0.625	0.814	0.878	0.183	0.573	0.759	0.816	0.143
	2007	0.620	0.818	0.884	0.157	0.555	0.733	0.798	0.135
	2008	0.630	0.793	0.904	0.192	0.563	0.705	0.813	0.172
	2009	0.646	0.838	0.916	0.183	0.579	0.763	0.821	0.152
	2010	0.638	0.822	0.921	0.171	0.571	0.733	0.821	0.158
	2011	0.655	0.844	0.923	0.199	0.580	0.727	0.832	0.181
	2012	0.631	0.836	0.902	0.156	0.563	0.721	0.822	0.146
	2013	0.678	0.797	0.823	0.413	0.590	0.690	0.765	0.314
	2014	0.689	0.779	0.837	0.451	0.598	0.675	0.781	0.339
New EU (113)	2005	0.692	0.846	0.899	0.330	0.665	0.845	0.874	0.275
	2006	0.710	0.868	0.895	0.368	0.688	0.871	0.889	0.304
	2007	0.697	0.861	0.895	0.334	0.658	0.845	0.864	0.265
	2008	0.686	0.828	0.894	0.337	0.631	0.793	0.847	0.253
	2009	0.700	0.886	0.921	0.293	0.641	0.837	0.855	0.231
	2010	0.703	0.860	0.914	0.334	0.656	0.846	0.877	0.246
	2011	0.706	0.855	0.908	0.355	0.653	0.821	0.869	0.268
	2012	0.689	0.885	0.899	0.284	0.648	0.836	0.874	0.233
	2013	0.741	0.910	0.847	0.465	0.662	0.844	0.836	0.306
	2014	0.759	0.899	0.868	0.511	0.683	0.829	0.857	0.362
Prob > |z| (Old country vs New country)	2005	0.000	0.002	0.000	0.000	0.196	0.000	0.002	0.000
	2006	0.000	0.036	0.000	0.000	0.141	0.000	0.000	0.000
	2007	0.000	0.000	0.000	0.126	0.060	0.001	0.157	0.407
	2008	0.500	0.003	0.000	0.005	0.000	0.000	0.683	0.008
	2009	0.740	0.864	0.000	0.738	0.000	0.000	0.299	0.277
	2010	0.735	0.181	0.020	0.391	0.002	0.000	0.407	0.234
	2011	0.808	0.361	0.003	0.485	0.002	0.000	0.284	0.541
	2012	0.081	0.421	0.975	0.041	0.011	0.000	0.010	0.008
	2013	0.006	0.678	0.000	0.035	0.041	0.000	0.000	0.201
	2014	0.007	0.475	0.001	0.003	0.002	0.000	0.000	0.148

Note1: Inefficiency score is defined from zero to one and a lower score represents better performance.

Note2: Aggregated inefficiency score equals to the average of inefficiency score of the three inputs.

Table 6. TFP change and contribution effect under CRS assumption

	year	TFP	Contribution effect of input			EFFCH	Contribution effect of input			TECHCH	Contribution effect of input		
			personnel expenses	total fixed assets	total deposits		personnel expenses	total fixed assets	total deposits		personnel expenses	total fixed assets	total deposits
All bank (927)	2005	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	2006	0.004	0.001	0.002	0.001	-0.035	-0.006	-0.004	-0.024	0.039	0.008	0.006	0.025
	2007	-0.002	0.001	0.002	-0.004	-0.028	-0.007	-0.006	-0.016	0.026	0.008	0.008	0.011
	2008	-0.004	-0.001	0.002	-0.006	-0.036	0.002	-0.012	-0.026	0.032	-0.002	0.014	0.020
	2009	0.006	0.000	0.004	0.001	-0.052	-0.014	-0.016	-0.021	0.057	0.014	0.020	0.022
	2010	0.011	0.001	0.005	0.005	-0.045	-0.008	-0.017	-0.020	0.056	0.009	0.022	0.024
	2011	0.014	0.001	0.008	0.005	-0.061	-0.015	-0.018	-0.029	0.075	0.016	0.025	0.034
	2012	0.023	0.002	0.011	0.010	-0.038	-0.013	-0.011	-0.013	0.060	0.015	0.022	0.023
	2013	0.026	0.002	0.012	0.012	-0.085	-0.003	0.014	-0.096	0.111	0.005	-0.002	0.108
	2014	0.032	0.003	0.014	0.015	-0.097	0.003	0.009	-0.109	0.128	-0.000	0.005	0.124
Old EU (814)	2005	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	2006	0.004	0.001	0.002	0.001	-0.037	-0.006	-0.005	-0.026	0.041	0.007	0.007	0.027
	2007	-0.005	-0.000	0.001	-0.006	-0.032	-0.007	-0.007	-0.017	0.027	0.007	0.008	0.012
	2008	-0.009	-0.002	0.001	-0.008	-0.042	0.001	-0.013	-0.029	0.033	-0.003	0.015	0.021
	2009	0.002	-0.000	0.004	-0.002	-0.058	-0.014	-0.017	-0.026	0.060	0.014	0.021	0.025
	2010	0.008	0.001	0.004	0.002	-0.050	-0.009	-0.019	-0.022	0.057	0.009	0.023	0.025
	2011	0.010	0.000	0.007	0.003	-0.067	-0.016	-0.020	-0.031	0.077	0.017	0.026	0.034
	2012	0.019	0.002	0.010	0.007	-0.043	-0.013	-0.013	-0.017	0.062	0.015	0.023	0.024
	2013	0.023	0.002	0.011	0.010	-0.090	-0.000	0.013	-0.103	0.113	0.002	-0.002	0.113
	2014	0.029	0.002	0.013	0.013	-0.101	0.005	0.009	-0.115	0.130	-0.003	0.004	0.129
New EU (113)	2005	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	2006	0.005	0.002	0.001	0.003	-0.019	-0.007	0.001	-0.013	0.024	0.009	-0.001	0.015
	2007	0.018	0.005	0.006	0.007	-0.005	-0.005	0.001	-0.001	0.023	0.010	0.005	0.009
	2008	0.030	0.009	0.010	0.011	0.005	0.006	0.002	-0.002	0.024	0.002	0.008	0.014
	2009	0.032	0.005	0.008	0.019	-0.009	-0.014	-0.007	0.012	0.040	0.018	0.016	0.007
	2010	0.037	0.005	0.010	0.022	-0.011	-0.005	-0.005	-0.001	0.048	0.010	0.015	0.023
	2011	0.045	0.007	0.014	0.024	-0.015	-0.003	-0.003	-0.008	0.060	0.010	0.017	0.032
	2012	0.047	0.003	0.016	0.027	0.003	-0.013	-0.000	0.015	0.044	0.016	0.016	0.012
	2013	0.048	0.003	0.016	0.029	-0.049	-0.021	0.017	-0.045	0.097	0.024	-0.001	0.074
	2014	0.052	0.005	0.019	0.028	-0.068	-0.018	0.010	-0.060	0.119	0.022	0.009	0.088

Note1: Accumulated productivity indicators and contribution effect scores are standardized with the year 2005 equal to zero.

Note2: Each productivity indicator score equals to the sum of contribution effects of inputs.

Table 7. TFP change and contribution effect under VRS assumption

	year	TFP	Contribution effect of input			EFFCH	Contribution effect of input			TECHCH	Contribution effect of input		
			personnel expenses	total fixed assets	total deposits		personnel expenses	total fixed assets	total deposits		personnel expenses	total fixed assets	total deposits
All bank (927)	2005	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	2006	0.011	0.003	0.007	0.002	-0.030	-0.008	-0.007	-0.015	0.041	0.011	0.013	0.016
	2007	0.005	0.002	0.006	-0.003	-0.011	0.001	-0.000	-0.011	0.016	0.002	0.007	0.007
	2008	-0.005	-0.003	0.004	-0.006	-0.015	0.011	-0.004	-0.021	0.010	-0.014	0.008	0.016
	2009	0.007	-0.001	0.006	0.002	-0.029	-0.008	-0.007	-0.015	0.036	0.007	0.013	0.016
	2010	0.015	0.000	0.010	0.005	-0.024	0.000	-0.008	-0.017	0.040	-0.000	0.017	0.022
	2011	0.017	-0.000	0.012	0.005	-0.032	0.003	-0.011	-0.025	0.049	-0.003	0.022	0.030
	2012	0.026	0.001	0.016	0.009	-0.017	0.004	-0.008	-0.013	0.043	-0.003	0.024	0.022
	2013	0.032	0.002	0.019	0.012	-0.042	0.013	0.010	-0.065	0.074	-0.011	0.008	0.077
	2014	0.038	0.003	0.021	0.014	-0.051	0.018	0.005	-0.075	0.089	-0.015	0.016	0.089
Old EU (814)	2005	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	2006	0.012	0.004	0.007	0.001	-0.031	-0.008	-0.007	-0.016	0.043	0.012	0.014	0.017
	2007	0.004	0.003	0.007	-0.006	-0.013	0.001	-0.001	-0.013	0.017	0.002	0.008	0.007
	2008	-0.010	-0.005	0.004	-0.009	-0.021	0.010	-0.006	-0.025	0.011	-0.015	0.010	0.016
	2009	0.002	-0.002	0.005	-0.002	-0.037	-0.009	-0.009	-0.019	0.039	0.008	0.014	0.017
	2010	0.012	-0.000	0.010	0.002	-0.029	0.000	-0.008	-0.021	0.041	-0.001	0.019	0.023
	2011	0.013	-0.001	0.012	0.002	-0.038	0.003	-0.012	-0.028	0.051	-0.004	0.024	0.030
	2012	0.023	0.001	0.016	0.007	-0.021	0.005	-0.009	-0.017	0.044	-0.004	0.025	0.024
	2013	0.030	0.002	0.019	0.010	-0.048	0.015	0.010	-0.073	0.078	-0.013	0.009	0.083
	2014	0.037	0.003	0.021	0.013	-0.056	0.020	0.005	-0.081	0.093	-0.017	0.017	0.094
New EU (113)	2005	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	2006	0.005	-0.001	0.001	0.005	-0.023	-0.008	-0.005	-0.010	0.028	0.008	0.006	0.015
	2007	0.018	0.001	0.003	0.013	0.007	0.000	0.003	0.003	0.011	0.001	-0.000	0.010
	2008	0.031	0.006	0.008	0.018	0.033	0.017	0.009	0.007	-0.002	-0.011	-0.001	0.010
	2009	0.040	0.005	0.010	0.024	0.024	0.003	0.006	0.015	0.016	0.003	0.004	0.009
	2010	0.036	0.002	0.008	0.026	0.009	-0.000	-0.001	0.010	0.028	0.003	0.008	0.017
	2011	0.044	0.005	0.013	0.027	0.012	0.008	0.002	0.002	0.032	-0.003	0.011	0.024
	2012	0.047	0.003	0.017	0.026	0.017	0.003	-0.000	0.014	0.030	0.000	0.017	0.012
	2013	0.047	0.003	0.018	0.025	0.002	0.000	0.013	-0.010	0.045	0.003	0.006	0.036
	2014	0.047	0.005	0.019	0.023	-0.018	0.005	0.006	-0.029	0.065	-0.001	0.013	0.052

Note1: Accumulated productivity indicators and contribution effect scores are standardized with the year 2005 equal to zero.

Note2: Each productivity indicator score equals the sum of contribution effects of inputs.

Table 8: Phillips and Sul Log*t* convergence test on productivity indicator and inefficiency score of individual inputs

	All EU (28)		Old EU (15)		New EU (13)	
	γ	*t*-stat	γ	*t*-stat	γ	t-stat
TFP	-2.976	-2.204 *	-2.955	-3.092*	-11.023	-6.893*
EFFCH	1.570	0.898	-1.150	-29.551*	-2.596	-4.345*
TECHCH	3.813	1.968	4.410	1.686	1.905	1.341
Personnel expenses	-1.125	-23.181*	-1.130	-33.045*	-1.037	-5.448*
Fixed asset	-1.054	-16.417*	-1.066	-18.792*	-0.849	-2.529*
Deposits	-0.363	-0.681	-0.362	-0.630	-0.360	-1.324

*Note:** Indicates rejection of the null hypothesis of convergence at the 5% significance level.

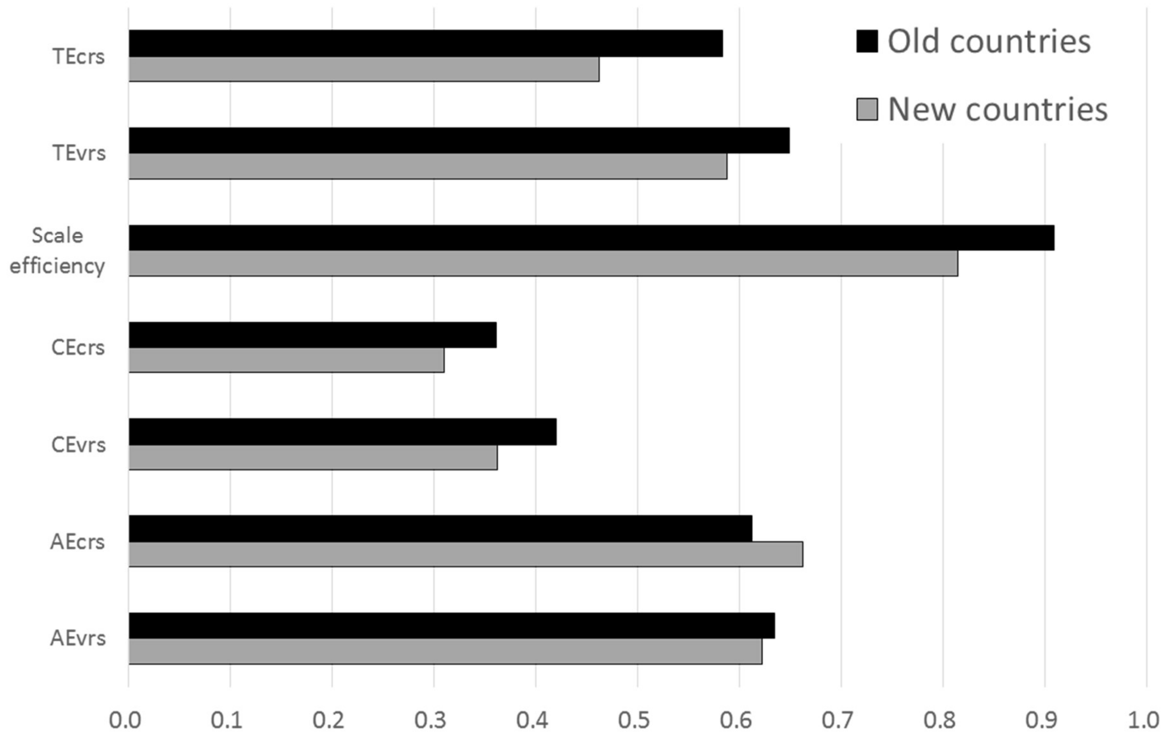

Figure 1 Bank efficiency scores

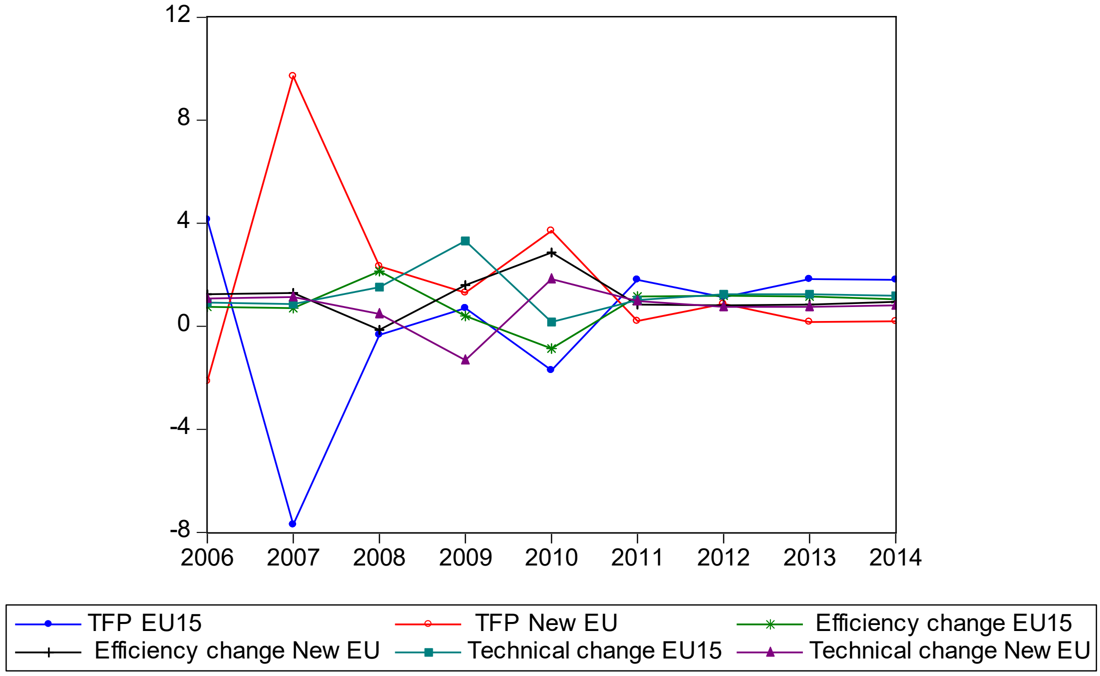

Figure 2 Transition paths for TFP and efficiency /technical change

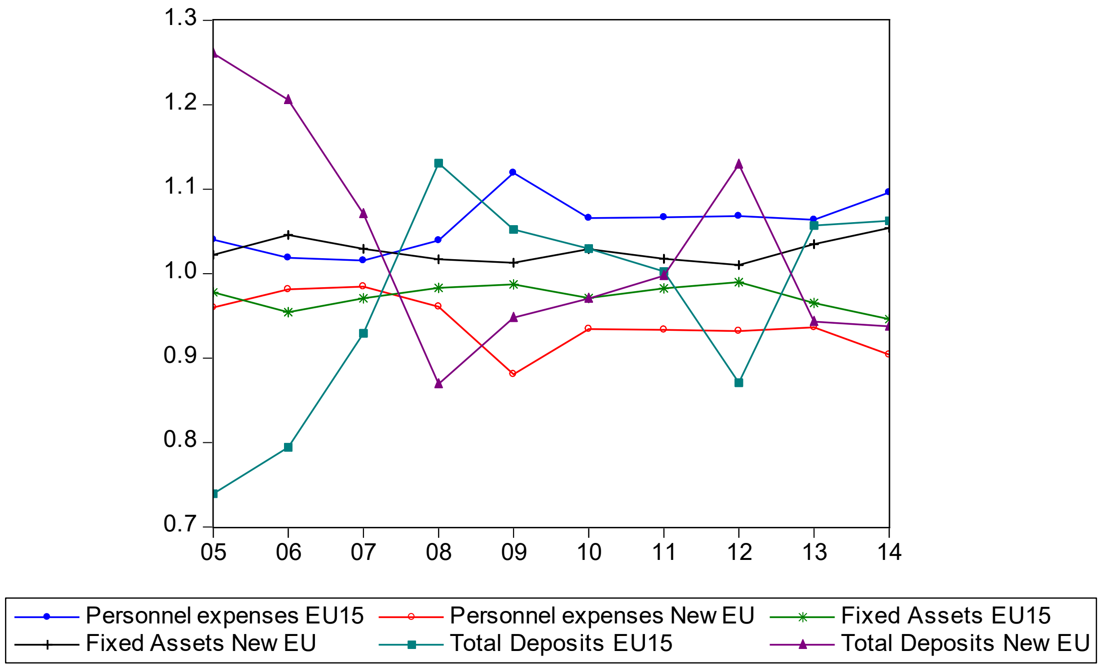

Figure 3 Transition paths for inefficiency scores for individual inputs x1, x2 and x3