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Efficiency of the banks: the case of the Visegrad countries

Abstract. The purpose of the paper is to measure the technical efficiency of domestic commercial banks in the Visegrad countries (V4) by using non-parametric Data Envelopment Analysis (DEA) and estimate the efficiency change in the banking sector. We apply an input-oriented window DEA model with a constant and variable return to scale to investigate the technical efficiency of commercial banks' deposits to loan the transformation process. The input-oriented model was evaluated using CCR (a measure of the overall technical efficiency) and BCC (a measure of the pure technical efficiency). The model results provide recommendations for managers in managing banks to increase their effectiveness in the analysed group of banks. The analysis is focused on the 2005-2016 period, since the banking went through massive structural and regulatory changes and was affected by the 2008 financial crisis during this period. To obtain the best research results, we considered three sub-periods (2005-2008; 2009-2012; 2013-2016). The growth of the banking market, as well as the development of the economy, has led to changes in the technical efficiency. Therefore, the last part of this paper is focused on the determinants of the efficiency changes relating to individual sub-periods identified by using the radial Malmquist index under the condition of constant return to scale.
The results point to the fact that the positive efficiency change during the 2005-2008 period was primarily due to the innovation and technological growth, while during the 2009-2012 and 2013-2016 periods it was mostly impacted by progress in the efficiency change due to improved operations of management and return to scale effect.
Taking into account the results of the BCC model, which overcome the assumption that banks operate under the condition of their optimal size, we can see that the leading position was reached by the Hungarian banking sector, whose average pure technical efficiency was 78.83% during the whole analysed period. The Czech Republic ranked second, with the average pure technical efficiency equal to 68.63%, the third one was Poland (60.52%), the last one was the Slovak banking sector (58.32%).
Data relevant to the years 2018 and 2017 were not available at the time of the analysis, therefore the authors present only a trend of future development. Data provided by the European Central Bank which are partially available for 2017 suggest that the development described by the analysis results with the use of the DEA models covering all the three sub-periods will have an increasing trend with digressive slope.
Keywords: Window Data Envelopment Analysis (DEA); Intermediation Approach; Malmquist Index; Commercial Banks; Banking; Return to Scale Effect; Technical Efficiency; CCR; BCC; Visegrad Countries (V4)
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Ефективність діяльності банків на прикладі країн Вишеградської групи
Анотація. Метою цієї статті є вивчення технічної ефективності комерційних банків у країнах Вишеградської групи з використанням непараметричного методу аналізу охоплення даних, а також оцінка зміни ефективності управління в банківському секторі. Для проведення дослідження авторами статті було застосовано модель, орієнтовану на вхідні дані з метою дослідження технічної ефективності депозитів комерційних банків для кредитування процесу трансформації. Висновки, зроблені на основі отриманих результатів дослідження, дозволяють сформулювати рекомендації щодо підвищення ефективності управління банками.
Дослідження охоплює період 2005–2016 років, оскільки в цей період банківський сектор зазнав значних структурних змін. Також зазначений період вважається періодом виникнення фінансової кризи. Для більш повного відображення результатів дослідження автори розділили його на три підперіоди: 2005–2008 рр., 2009–2012 рр., 2013–2016 рр. При цьому наголошується, що зростання банківського сектора та розвиток економіки привели до змін, які стосуються технічної ефективності. У зв'язку з цим в останній частині цієї статті увагу приділено детермінантам зміни ефективності в окремо взяті періоди з використанням індексу Мальмквіста. Отримані результати підтверджують той факт, що позитивні зміни, які стосуються ефективності за період 2005–2008 років були, головним чином, обумовлені інноваційним розвитком і технологічним зростанням, тоді як за період 2009–2012 та 2015–2016 років на ситуацію вплинув прогрес, пов'язаний із поліпшенням управління. На момент проведення дослідження дані за період 2017–2018 рр. не були доступні, у зв'язку з чим авторами було визначено тільки загальну тенденцію майбутнього розвитку.
Дані, які охоплюють 2017 рік, були надані Європейським центральним банком. На їх основі стало можливим спрогнозувати, що передбачуваний розвиток матиме позитивну тенденцію з деякими відхиленнями від наміченого курсу.
Ключові слова: аналіз охоплення даних; посередницький підхід; індекс Мальмквіста; комерційні банки; банківська справа; ефект масштабу; країни Вишеградської групи.

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Эффективность банковской деятельности на примере стран Вышеградской группы

Аннотация. Целью данной статьи является изучение технической эффективности коммерческих банков в странах Вышеградской группы с использованием непараметрического метода анализа охвата данных, а также оценка изменения эффективности управления в банковском секторе. В ходе проведения исследования авторами статьи была применена модель, ориентированная на входные данные, с целью исследования технической эффективности депозитов коммерческих банков для кредитования процесса трансформации. Выводы, сделанные на основе полученных результатов исследования, позволяют сформулировать рекомендации касательно повышения эффективности управления банками. Данное исследование охватывает период 2005–2016 годов, поскольку в этот период банковский сектор претерпел значительные структурные изменения. Также указанный период считается периодом возникновения финансового кризиса. Для более полного отображения результатов исследования авторы разделили его на три подпериода: 2005–2008 гг., 2009–2012 гг., 2013–2016 гг. При этом отмечается, что рост банковского сектора и развитие экономики привели к изменениям, затрагивающим техническую эффективность. В связи с этим в последней части данной статьи внимание уделено детерминантам изменения эффективности в отдельно взятые подпериоды с использованием индекса Мальмквиста. Полученные результаты подтверждают тот факт, что положительные изменения эффективности в период 2005–2008 годов были обусловлены, главным образом, инновационным развитием и технологическим ростом, тогда как в период 2009–2012 и 2015–2016 годов влияние оказал прогресс в измерении эффективности, связанный с улучшением управления. На момент проведения исследования данные за период 2017–2018 гг. не были доступны, в связи с чем авторами была определена только общая тенденция будущего развития.
Доступные данные, за 2017 год, которые, были предоставлены Европейским центральным банком, позволили спрогнозировать, что предполагаемое развитие будет иметь положительную тенденцию с некоторыми отклонениями от намеченного курса.

Ключевые слова: анализ охвата данных; посреднический подход; индекс Мальмквиста; коммерческие банки; банковское дело; эффект масштаба; страны Вышеградской группы.

1. Introduction

During the global financial crisis, the global banking sector has been facing a series of problems since 2008. The issues that have decimated the overall net profit not only increased both the credit risk and costs in line with the new regulatory framework, but also affected other aspects of banking industry like competition, efficiency and stability. We can see that before the interbank market was very active the year 2008, and banks were lending money with high confidence. The situation has changed since then, and many banks have severe problems when finding resources of liquidity other than deposits. Many countries have faced either a significant decline in their growth rate or even recession (Kiseľáková & Kiseľák, 2013).

The financial markets in the Visegrad countries can be characterised as representatives of a bank-oriented financial market where a critical part of financial transactions is carried out through the financial intermediaries. The group of Visegrad countries (V4) includes the Czech Republic (CR), Hungary (HU), Poland (PL) and Slovakia (SR). Using data about the global financial development published by World Bank, we can see that, for example only 30% of financial transactions was carried out through the financial market (debt securities and stock market) in Slovakia in 2015 and 70% was carried out through deposit money banks and other financial institutions. In the case of the Czech Republic, the ratio was approximately 40:60; it was 45:55 for Poland, and it equalled 50:50 for Hungary. In the Visegrad countries, a critical part of financial transactions realised by financial intermediaries is carried out through commercial banks, which play the role of principal financial intermediaries. This fact is evident from data by the Word Bank, where, in the case of Slovakia, the Czech Republic, Hungary and Poland in 2015, commercial banks managed around 70% of financial assets, and only 30% was managed by insurance companies, mutual funds, nonbank financial institutions and pension funds. That is why it is necessary to evaluate the efficiency of the process where funds transform from creditors to debtors. Conservative measures, such as financial ratios, are still present when assessing banks' efficiency. More sophisticated methods are aimed at measuring the overall efficiency, taking multiple inputs and multiple outputs into account. Data Envelopment Analysis (DEA) is one of them and allows to create the so-called reference group of units with the best practice regarding efficiency and to determine which of the units are inefficient compared to those in the reference group, as well as to provide a measurable scale of the inefficiencies present. Another advantage of the DEA method is that it should bring recommendations for managers in managing banks to increase their efficiency in the analysed group of banks. It can bring proposals on how to control the input or output variables with the aim to minimise input at a given level of output, or how to maximise output at a given level of input.

In this paper, a DEA window analysis is used to evaluate the efficiency of commercial banks within three sub-periods that aggregate years with similar characteristics. An input-oriented model with a constant and variable return to scale is applied to investigate the efficiency of deposits to loan the transformation process. The last part of this paper focuses on the determinants of efficiency changes within individual sub-periods using the radial Malmquist index under the condition of constant return to scale. In addition to that objective, we deal with the following research questions about whether the banking sector of the Visegrad countries performs efficiently, the primary sources of inefficiency, whether there is any way how the managers of commercial banks can improve the efficiency of the transformation process in the Visegrad countries, whether the efficiency of the transformation process (transformation of the deposits to loans) in the Visegrad countries has changed over the past years, including the determination of the main reason for the positive/negative efficiency change in the Visegrad countries? The answer to these questions may be beneficial to the three main groups. Knowledge of the efficiency score is essential to bank managers since it reflects the quality of daily operations in utilising inputs and outputs. Also, other decisions can be based on that knowledge. Policymakers are the second group that may benefit from the relevant information because they can use it to compare the efficiency of the banking sector before and after the regulation changes took place and, consequently, they can evaluate whether the regulation changes were beneficial to the banking sector. Finally, it is researchers who can also benefit as they can use previous studies in that area to observe the gradual development in the field of efficiency measurement, which can enable them to identify gaps in the research area.

2. Brief Literature Review

H. Sherman and F. Gold (1985) were the first to apply DEA in the banking sector. They used DEA to evaluate the operating efficiency of 14 saving bank branches. In their study, they not only measured the level of efficiency but also defined how to eliminate inefficiency by adjusting inputs and outputs of inefficient bank branches. J. Pastor et al. (1997) analysed the efficiency of several US and European banks using the value-added approach for comparability to define the inputs and outputs. B. Casu and P. Molyneux (2003) used the intermediation approach to evaluate the efficiency of 750 selected European banks. The results showed relatively low average efficiency scores. Nevertheless, it was possible to detect a slight improvement in efficiency levels through time.

The Malmquist index approach was used in the paper by M. Degl'Innocenti et al. (2017) who estimated productivity growth of commercial banks in the 28 European Union countries and the process of bank integration during the three main stages of the global financial crisis. They analysed the sources of growth in different stages of production using a two-stage DEA model. The result showed a productivity growth during 2007-2008, but a consistent decline during 2009-2010. The loss of competitiveness was due to the drop in growth in the performance stage and technical change.

Besides this study, many studies assess the productivity change in the European banking industry. S. Berg et al. (1992), G. Battesse et al. (2000), S. Kumbhakar et al. (2001), B. Casu et al. (2004, 2016) focused on either the impact of financial regulation on the productivity of banks in a single country context or an international institutional setting. In general, they found out technical progress and productivity growth in the European banking system due to the liberalisation process.

In the Czech Republic, Hungary, Poland, Slovakia and Ukraine, Data Envelopment Analysis has been used to measure the efficiency of financial institutions in the last years. For example in the works by J. Jablonský (2012), I. Řepková (2014), E. Zimková (2014), M. Boďa & E. Zimková (2015), I. Palečková (2015), L. Černohorská et al. (2017), I. Palečková (2017), V. Ponomarenko et al. (2017), M. Tollo et al. (2018) and others. J. Jablonský (2012) estimated technical efficiency based on the sample of 194 bank branches of one of the Czech commercial banks. He also presented the application of DEA for ranking efficient units. I. Řepková (2014) used DEA to analyse the data of Czech commercial banks and estimated efficiency during the 2003-2012 period. She identified that the average efficiency under the constant return to scale condition reached 70-78%, and under a variable return to scale condition it reached 84-89%. Larger banks scored a lower efficiency than other banks in the banking industry, mostly due to the excess of deposits in balance sheets and inappropriate size of operations. E. Zimková (2014) estimated the technical efficiency and the super-efficiency of commercial banks in Slovakia in 2012. She found out that more than one half of the institutions were found technically efficient by applying a primary input-oriented DEA model under the assumption of a variable return to scale. I. Palečková (2015) also analysed the technical efficiency and noticed an increase in the average technical efficiency of commercial banks in Slovakia between 2004 and 2013. M. Boďa and E. Zimková (2015) used three commonly applied (service-oriented, intermediation, and profit-oriented) approaches to compare the technical efficiency in the Slovak banking market over the 2000-2011 period. The result pointed to the fact that general impression of the efficiency status of individual banks obtained within the three approaches is similar in most cases.

The change of efficiency in Visegrad countries was analysed by L. Černohorská et al. (2017) who found out that changes across all states were relatively stable. Also, they found a substantial decline in the Malmquist index in the 2011-2012 period in Hungary. The Malmquist index remains stable during the 2011-2012 period for Poland and the Czech Republic and slightly declines for Slovakia.

I. Palečková (2017) estimated the efficiency change in the banking sector of the V4 countries during the 2009-2013 period and determined whether banks that belong to a financial conglomerate were more or less efficient than other banks in the industry. She uses Malmquist index and found out positive efficiency change during the 2009-2013 period, primarily due to innovation, superior management and technological growth.

3. Methods

DEA is one of the methods to measure the relative technical efficiency of production units (DMU) that use the same multiple inputs to produce various corresponding outputs. By applying DEA models on the available dataset, we can identify the efficient frontier and the efficiency score of each DMU. Each DMU can be using the DEA method easily visualised on the efficiency frontier and assessed regarding its efficiency. The efficiency calculated by the BCC model (Banker et al., 1984) is often called pure technical efficiency and is a component of the overall technical efficiency calculated by the CCR model (Charnes et al., 1978). The second efficiency component is the scale efficiency, which controls for the constant or variable return to scale condition. If the scale efficiency is equal to 1, the DMU (bank) operates under conditions of constant return to scale, which indicates that the bank runs at the most efficient scale size. If the scale efficiency is less than 1, the bank operates under conditions of variable return to scale, either increasing or decreasing.

We have decided to analyse their overall technical efficiency and pure technical efficiency within the three subperiods that had similar characteristics of the development of the banking sector in the country. Therefore, we used a three-window DEA. DEA window analysis uses a principle of moving averages and can be used when dealing with small data samples. DEA window analysis was proposed by A. Charnes et al. (1985) to measure efficiency in cross-sectional and time-varying data. According to A. Charnes et al. (1995), each DMU in a different period is treated as if it was a different DMU (independent) but remains comparable in the same window. This way the discriminatory power of DEA models can increase. As was presented by M. Asmild et al. (2004) another advantage of DEA window analysis is that the efficiency of a production unit in a period can be contrasted against themselves and other units' overtime.

Following M. Asmild et al. (2004), we can consider $N\ DMUs$ (n = 1,2,…,N) observed in T (t = 1,2,…,T) periods using r inputs to produce s outputs. The sample, thus, has $N \times T$ observations, and an observation n in the period t, $DMU_n^{\,t}$ represents a DMU_n in period t with an r dimensional input vector $x_t^n = (x_{1t}^{\ n}, x_{2t}^{\ n}, \dots, x_{rt}^{\ n})$ and the s dimensional output vector $y_t^n = (y_{1t}^{\ n}, y_{2t}^{\ n}, \dots, y_{st}^{\ n})$. The window starting at time k, $1 \le k \le T$ and with the width w, $1 \le w \le T - k$, is denoted by k_w and has $N \times w$ observations. The matrix of inputs for this window analysis is given by:

$$X_{k_w} = (x_k^{\,1}, x_k^{\,2}, \dots, x_k^{\,N}, x_{k+1}^{\,1}, x_{k+1}^{\,2}, \dots, x_{k+1}^{\,N}, x_{k+w}^{\,1}, x_{k+w}^{\,2}, \dots, x_{k+w}^{\,N}) . \quad (1)$$

And the matrix of outputs is given by:

$$Y_{k_w} = (y_k^{\,1}, y_k^{\,2}, \dots, y_k^{\,N}, y_{k+1}^{\,1}, y_{k+1}^{\,2}, \dots, y_{k+1}^{\,N}, y_{k+w}^{\,1}, y_{k+w}^{\,2}, \dots, y_{k+w}^{\,N}) . \quad (2)$$

The following form can give the input-oriented DEA window problem under a constant return to scale assumption:

$$\begin{aligned} &\theta'_{k_w t} = \min_{\theta,\lambda} \theta \\ &\text{s.t.} \quad -X_{k_w}\lambda + \theta x'_t \ge 0 \\ &Y_{k_w}\lambda - y'_t \ge 0 \\ &\lambda_n \ge 0 \quad (n = 1,\dots, N \times w) . \end{aligned} \quad (3)$$

After the overall technical efficiency and pure technical efficiency estimation, we performed an analysis of factors determining the efficiency change over. For this purpose, we used the Malmquist index with its decomposition into the driving forces of productivity change. The Malmquist index measures total factor productivity change between two data points «by calculating the ratio of distances of each data point relative to standard technology» (Adeleke et al., 2017). Following R. Shephard (1953), R. Färe et al. (1994) and B. Casu et al. (2004) to define the Malmquist index, it is necessary to determine distance functions concerning two different periods. The Malmquist productivity index evaluates a productivity change of a DMU between two periods as the product of «catch-up» and «frontier shift» terms. The catch-up (recovery or efficiency change) term reflects the degree that a DMU attains for improving its efficiency, while the frontier shift (innovation or technological change) term demonstrates the difference in the efficient frontier surrounding the DMU between the two periods.

The following formula can measure the catch-up effect from period 1 to period 2:

$$Catch-up = \frac{Efficiency\ of\ (x_O,y_O)\ in\ period\ 2\ with\ respect\ to\ period\ 2\ frontier}{Efficiency\ of\ (x_O,y_O)\ in\ period\ 1\ with\ respect\ to\ period\ 1\ frontier}\ . \quad (4)$$

Next, we use the following notation for the efficiency score of DMU $(x_0, y_0)^{t_1}$ measured by the frontier technology t_2:

$$\delta^{t_2}((x_0, y_0)^{t_1}) \quad (t_1 = 1,2\ and\ t_2 = 1,2)\ . \quad (5)$$

Using this notation, we can express the catch-up effect as:

$$Catch-up = \frac{\delta^2((x_0, y_0)^2)}{\delta^1((x_0, y_0)^1)}\ . \quad (6)$$

If the «catch-up» effect value is greater than 1, it interprets the progress in the relative efficiency from period 1 to period 2. The «catch-up» effect value equal to 1 indicates no changes in the relative efficiency, and a value below 1 indicates a regress in relative efficiency.

In addition to the «catch-up» effect, the «frontier-shift» effect must be taken into account to fully evaluate the productivity change, since the «catch-up» effect is determined by the efficiencies being measured as the distances from the respective frontiers. According to W. Cooper et al. (2007), the frontier-shift (or innovation) effect reflects the change in the efficiency frontiers (production frontiers) between two periods. The frontier-shift is defined as follows:

$$Frontier-shift = \sqrt{\phi_1 \phi_2}\ , \quad (7)$$

where ϕ_1 and ϕ_2 are defined by the following formulas:

$$\phi_1 = \frac{Efficiency\ of\ (x_O,y_O)\ in\ period\ 1\ with\ respect\ to\ period\ 1\ frontier}{Efficiency\ of\ (x_O,y_O)\ in\ period\ 1\ with\ respect\ to\ period\ 2\ frontier},$$

$$\phi_2 = \frac{Efficiency\ of\ (x_O,y_O)\ in\ period\ 2\ with\ respect\ to\ period\ 1\ frontier}{Efficiency\ of\ (x_O,y_O)\ in\ period\ 2\ with\ respect\ to\ period\ 2\ frontier}\ . \quad (8)$$

Using previous notation (5), we can use the following formula representing the frontier-shift effect:

$$Frontier-shift = \left[\frac{\delta^1((x_0, y_0)^1)}{\delta^2((x_0, y_0)^1)} \times \frac{\delta^1((x_0, y_0)^2)}{\delta^2((x_0, y_0)^2)}\right]^{1/2}\ . \quad (9)$$

Frontier-shift higher than 1 indicates progress in the frontier technology around the evaluated production unit DMU (x_0, y_0), from period 1 to period 2, while frontier-shift equal to 1 and frontier-shift lower than one indicate the status quo and regress in the frontier technology.

The Malmquist index is computed as the product of the catch-up effect and frontier-shift effect. We obtain the following formula for the computation of the Malmquist index:

$$Malmquist\ index = \frac{\delta^2((x_0, y_0)^2)}{\delta^1((x_0, y_0)^1)} \times \left[\frac{\delta^1((x_0, y_0)^1)}{\delta^2((x_0, y_0)^1)} \times \frac{\delta^1((x_0, y_0)^2)}{\delta^2((x_0, y_0)^2)}\right]^{1/2}\ . \quad (10)$$

According to W. Cooper et al. (2007), the Malmquist index is a geometric mean of the two efficiency ratios: the one being the efficiency change measured by the period one technology and the other - the efficiency change measured by the period two technology. As can be seen from the formula (10), the Malmquist index consists of four terms: $\delta^1((x_0, y_0)^1)$, $\delta^2((x_0, y_0)^2)$, $\delta^1((x_0, y_0)^2)$, and $\delta^2((x_0, y_0)^1)$. The first two are related to the measurements within the same period with t = 1 or t = 2, while the last two are for intertemporal comparison. The Malmquist index higher than 1 indicates progress in the total factor productivity change of the evaluated production unit DMU (x_0, y_0), from period 1 to period 2. The Malmquist index equal to 1 shows a status quo, and the Malmquist index lower than one means deterioration in the total factor productivity.

4. Data, Results and Discussions

In this research, we focus on the overall and pure technical efficiency evaluation of commercial banks in the Visegrad countries between 2005 and 2016. The analysis used banks' data that cover more than 76% of the total banking assets in case Czech Republic in 2016, more than 46% in the case of Hungary, more than 36% in the case of Poland and more than 80% in the case of Slovakia. We created a panel of 40 universal commercial banks operating in Visegrad countries (twelve from Hungary, eleven from the Czech Republic, six from Poland and eleven from Slovakia's banking market during the analysed period. The reason for older data exclusion was that the new Basel II rules were implemented in 2004.

We use the three sub-periods (windows) DEA analysis, which works on the moving averages principle. The first sub-period (2005-2008) was characterised by the accession of the Czech Republic, Hungary, Poland and the Slovak Republic to the European Union and significant changes in the operation of commercial banks in the structure of their services and the orientation on mortgage banking and asset management. The adoption of the Euro as the national currency in Slovakia characterised the second sub-period (2009-2012). During this period, the banking market in all the V4 countries developed, which was also influenced by the financial crisis that hit banking sectors all around the world in 2008 (Pitoňáková, 2015). The last sub-period (2013-2016) was characterised by non-standard operations of the European Central Bank (ECB), the policy of negative interest rates and the tightening regulation of the national central banks in the V4 countries in the retail lending. The implementation of capital buffers, in line with the implementation of Basel III, also characterised this period.

To evaluate the «relative» technical efficiency, the intermediation approach was used, since the main role of commercial banks is the realisation of financial intermediation. The term «relative» refers to the achieved efficiency within the group and under selected criteria (the input and the output variables according to the intermediation approach). In our analysis, we compare the relative technical efficiency of each bank and also the average efficiency of banks in the banking sector according to the bank's headquarters in one of the four countries of the V4 group. The calculation was done using the DEA Solver-Pro software (http://www.saitech-inc.com/products/prod-dsp.asp) and MS Excel.

As the clients' deposits are the main source of funds, and loans are the main part of the assets side of the balance sheet, we decided to use deposits as the input and loans as the output variable. We selected the number of employees as an input variable because their employees provide most of the bank services. We decided to limit the number of the input and the output variables (accepting the rule that the number of DMUs should be three times the number of the variables) to avoid the unreasonably high-efficiency scores in the estimation. We extracted the data from the Bankscope database (bankscope.bvdinfo.com), and we supplemented the missing data from the banks' annual reports on an unconsolidated basis. We reported all the data in EUR as the reference currency. The figures in national currencies (HUF, CZK and PLN) were converted by the official exchange rates of national central banks at the end of the analysed year. Table 1 and Figure 1 give descriptive statistics of the variables used in the analysis.

As can be seen from our sample, the Polish banking sector could be considered as the largest one with the average number of employees equal to 8,285 persons, the average deposit value of EUR 10,938,447 thousand and the average loans amounting to EUR 9,316,478 thousand during the whole analysed period. On the other hand, the banking sector in Slovakia can be considered to be the smallest, with the average number of employees equal to 1,346, the average deposit value of EUR 2,980,393 thousand and the average loans amounting to EUS 2,545,290 thousand during the whole analysed period. The development of input and output average values during the examined period in individual countries in Figure 1 shows that the volume of total loans, deposits and number of employees had significantly risen by 2008. During the first sub-period, the amount of deposits increased by more than 49% in the Czech Republic, more than 54% in Hungary, more than 59% in Poland and more than 91% in Slovakia. The volume of loans increased during the first sub-period by more than 90% in the Czech Republic, more than by 80% in Hungary, more than by 104% in Poland and more than by 58% in Slovakia. In the case of the last variable, a significant increase in the number of employees during the first sub-period can be seen in Hungary (more than 57%) and Poland (more than 28%). The 2009 financial crisis temporary stopped this growth. Therefore, during the second sub-period (2009-2012) the deposit increased only by 17% in the Czech Republic, by 16% in Poland and by 7% in Slovakia. In the case of Hungary, we can observe a decrease in the deposit value. A similar situation can be seen in case of the second variable, where the total amount of loans increased only by 23% in the Czech Republic and Poland, by 10% in Slovakia, and decreased by 11% in Hungary. In the case of the number of employees, an increase can be observed in the Czech Republic (3%) and Hungary (4%), whereas the number of employees decreased in Poland (4%) and Slovakia (3%). During the last sub-period the renewal of growth can be seen in the Czech Republic (an increase in deposits by 21%, loans by 16% and the number of employees by 3%), Poland (an increase of deposits by 25%, loans by 25% and the number of employees by 2%), and Slovakia (an increase of deposits by 17%, loans by 25% and the number of employees by 4%). On the other hand, in Hungary, the renewal of growth can be seen only in terms of deposits (by 5%), while for loans and the number of employees the downward trend continued.

Data from 2018 and 2017 were not available at the time of this analysis. Therefore, only a trend of future development is presented by the authors. Data partially available for 2017 by the European Central Bank, suggest that the development described by the analysis results using the DEA models in all the three sub-periods would have an increasing trend with digressive slope. In 2017, the volume of total loans have increased in all the V4 countries, especially in the Czech Republic (by 43%), followed by Slovakia (by 11%), Poland (by 10%) and Hungary (by 6.9%). From the point of view of deposits, the highest increase was in Czech Republic (27%), followed by Hungary (10.9%), Poland (9.5%) and Slovakia (5.2%). An increase in the number of employees was recorded in the case of the Czech Republic (0.84%) and Hungary (0.32%). Slovakia and Poland recorded a decrease by 4.6% and 2.5%, respectively.

In general, this development trend is in line with trends within the third analysed sub-period.

Following the described methodology, the efficiency of all banks in the three sub-periods (2005-2008; 2009-2012; 2013-2016) using CCR (a measure of the overall technical

Tab. 1: **Descriptive statistics of variables entering into the model**

		Number of employees	Total deposits (EUR th)	Total loans (EUR th)
2005-2008	Minimum	36	4 467	10 953
	Maximum	33 085	21 586 786	22 743 470
	Average	3 594	4 482 666	3 666 984
	St. deviation	5 498	5 396 557	4 179 120
2009-2012	Minimum	35	2 513	2 600
	Maximum	36 366	27 464 182	26 379 967
	Average	3 877	6 067 121	5 364 384
	St. deviation	6 130	7 137 955	6 035 153
2013-2016	Minimum	75	4 821	68 813
	Maximum	38 203	30 763 592	28 974 483
	Average	3 960	7 305 497	6 251 364
	St. deviation	6 690	8 552 882	7 266 954
2005-2016	Minimum	35	2 513	2 600
	Maximum	38 203	30 763 592	28 974 483
	Average	3 810	5 951 761	5 094 244
	St. deviation	6 115	7 224 905	6 047 242

Source: Compiled by the authors

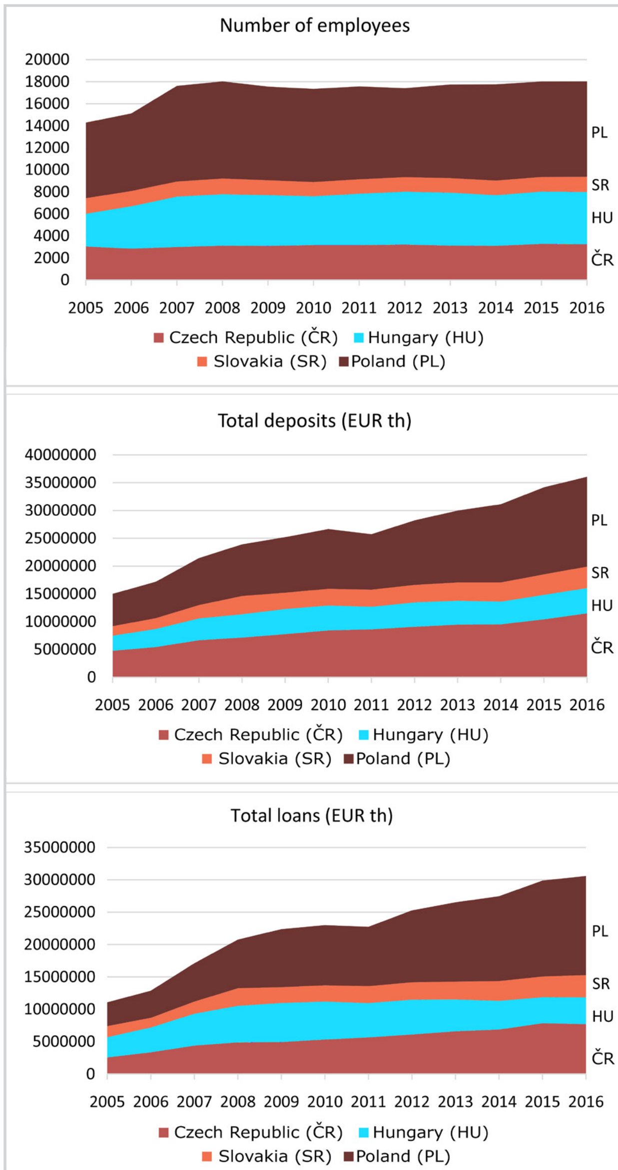

Fig. 1: **Development of average values of input and output variables**
Source: Compiled by the authors

efficiency) and BCC (a measure of the pure technical efficiency) the input-oriented model was evaluated. In Figure 2, the distributions of efficiencies in each of the sub-periods are presented using the CCR or BCC model.

The CCR model reported an increase of the overall technical efficiency medians from the first to the second period (by 17.7%) with an increase (21.04%) towards the third one (the median values of 38.48% were within the first period, 45.29% within the second period and 54.83% within the third period). A slower increase in the median values between the first and second sub-period can also be explained by the financial crisis that hit the banking sectors all around the world in 2008. The CCR overall technical efficiency can be decomposed into the BCC pure technical efficiency and the scale efficiency. We used the BCC model due to the other than the optimal size operation of the banks. The pure technical efficiencies were higher during all the analysed periods (the median values of 57.23% were within the first period, 66.71% within the second period, and 75.56% within the third period) due to the existence of scale inefficiency and the non-optimal size of banks. Based on the above sample, we can say that most banks operated under the conditions of variable return to scale, mostly decreasing return to scale. In view of the results presented in Figure 2, a higher variability can be seen under the CCR model, especially during the second sub-period.

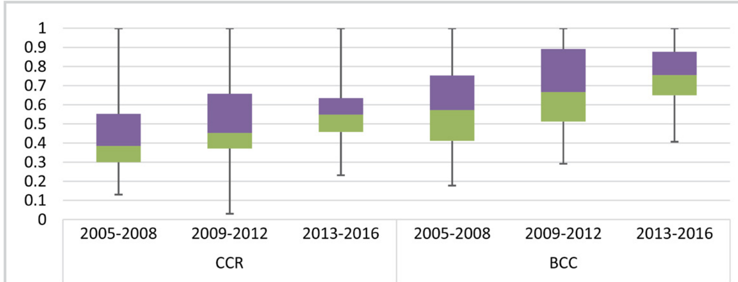

Fig. 2: **The results of DEA models in the three sub-periods in the V4 countries**
Source: Compiled by the authors

We calculated the level of average efficiency separately for each state to observe differences in the average efficiency among the V4 countries. Table 2 presents the results.

Taking into account the results of the BCC model, which overcome the assumption that banks operate under the condition of their optimal size, we can see that the leading position was reached by the Hungarian banking sector, whose average pure technical efficiency was 78.83% during the whole analysed period. The Czech Republic ranked second, with the average pure technical efficiency equal to 68.63%. The third one was the banking sector in Poland, where the average pure technical efficiency gains value of 60.52%. The last was the Slovak banking sector, where the average pure technical efficiency was only 58.32%. Hungarian banks reached the highest efficiency during the 2005-2014 period. In 2015 and 2016, Polish banks were the most efficient. The Polish banking sector reached the highest improvement of efficiency between the first and last year of the analysed period, where the average pure technical efficiency increased by 138%. The slowest increase can be seen in Hungary, where the average efficiency increased only by 10%. According to the CCR model, the most efficient was the banking sector in Hungary, the second was in the Czech Republic, the third was in Slovakia and the last was the Polish banking sector. The highest improvement can also be seen in the case of Poland (126%), in Slovakia (94%), the Czech Republic (58%), and the last one is the Hungarian banking sector (16%).

One of the significant advantages of DEA is the ability to identify potential areas for the improvement of inefficient banks. The input-oriented model brings recommendations for inefficient bank how to become efficient by reduction on the inputs side. The identification of the sources of inefficiency may help to remove some barriers on the way to catch up with more efficient banks in the money lending business. We can see (Table 3) that, in order to improve the efficiency, it was necessary to reduce the value of inputs by 40% on average in the model with constant return to scale assumption, and by 22% in the model with a variable return to scale assumption. The highest reduction rate was required at the beginning of the analysed period when the average efficiency score was the lowest one. If we look at the reduction rates separately according to the examined countries, we find that the highest reduction was required in the case of Polish banks (45.5%) in the model with constant return to scale assumption, and in the case of Slovak banks (26.15%) in the model with variable return to scale assumption.

In the next part, we analyse the relationship between pure technical efficiency (BCC) and the bank size, using the total deposit and total loans amount as the proxy of its size. As the value of total deposit (TD) and total loans (TL) has relatively high volatility (as is evident in Table 1), we have decided to transform it into a logarithmic form. In Figure 3, we plot the BCC efficiency against the bank size during the whole analysed period. In each case, we consider both linear and nonlinear fitted values. We obtained the R-square by finding a linear or quadratic function. We can see a relatively weak linear relationship between the pure technical efficiency and the bank size. More importantly, scatter plots reported in Figure 3 indicate a potential nonlinear link between the pure technical efficiency and the bank size. Following the theoretical results from D. Martinez-Miera and R. Repullo (2010), such a nonlinear investigation of nonlinear relationship can

Tab. 2: **Average technical efficiency in the V4 countries**

Country average	Model	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
CR	CCR	0.4032	0.4553	0.4886	0.5173	0.5091	0.5209	0.5183	0.5467	0.5918	0.5865	0.6384	0.6363
	BCC	0.5427	0.6159	0.7057	0.6960	0.6616	0.6629	0.6548	0.6696	0.7190	0.7202	0.7987	0.7881
HU	CCR	0.5282	0.5457	0.5841	0.6508	0.6514	0.6083	0.5996	0.6066	0.6151	0.6143	0.5811	0.6144
	BCC	0.7142	0.7373	0.7875	0.8404	0.8497	0.8259	0.7747	0.7910	0.7983	0.8030	0.7516	0.7861
PL	CCR	0.2406	0.2598	0.3074	0.3485	0.4073	0.3988	0.4027	0.4583	0.4918	0.5054	0.5135	0.5448
	BCC	0.3486	0.3592	0.4252	0.5167	0.6158	0.5957	0.5920	0.6847	0.7291	0.7578	0.8095	0.8283
SR	CCR	0.2985	0.3355	0.3844	0.4422	0.4483	0.4747	0.4685	0.4851	0.4985	0.5432	0.5510	0.5777
	BCC	0.3804	0.4142	0.4729	0.5620	0.5553	0.5877	0.5949	0.6249	0.6464	0.7077	0.7140	0.7385
V4	CCR	0.3875	0.4201	0.4614	0.5114	0.5198	0.5161	0.5116	0.5344	0.5581	0.5708	0.5784	0.5999
	BCC	0.5204	0.5583	0.6242	0.6756	0.6820	0.6810	0.6649	0.6960	0.7244	0.7473	0.7629	0.7799

Source: Compiled by the authors

Tab. 3: **Reduction rate (in %) to improve efficiency in V4 countries**

Country average	Model	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
CR	CCR	59.68	54.47	51.14	48.27	49.09	47.91	48.17	45.33	40.82	41.35	36.16	36.37
	BCC	45.73	38.41	29.43	30.40	33.84	33.71	34.52	33.04	28.10	27.98	20.13	21.19
HU	CCR	47.18	45.43	41.59	34.92	34.86	39.17	40.04	39.34	38.49	38.57	41.89	38.56
	BCC	28.58	26.27	21.25	15.96	15.03	17.41	22.53	20.90	20.17	19.70	24.84	21.39
PL	CCR	75.94	74.02	69.26	65.15	59.27	60.12	59.73	54.17	50.82	49.46	48.65	45.52
	BCC	65.14	64.08	57.48	48.33	38.42	40.43	40.80	31.53	27.09	24.22	19.05	17.17
SR	CCR	70.15	66.45	61.56	55.78	55.17	52.53	53.15	51.49	50.15	45.68	44.90	42.23
	BCC	61.96	58.58	52.71	43.80	44.47	41.23	40.51	37.51	35.36	29.23	28.60	26.15
V4	CCR	61.25	57.99	53.86	48.86	48.02	48.39	48.84	46.56	44.19	42.92	42.16	40.01
	BCC	47.96	44.17	37.58	32.44	31.80	31.90	33.51	30.40	27.56	25.27	23.71	22.01

Source: Compiled by the authors

be useful from a policy point of view, as it allows identifying an optimal threshold beyond which the bank size becomes dangerous for the performance and of the whole banking sector. For the relationship between the total deposits, total loans and pure technical efficiency, we report the turning point (i.e. the optimal threshold). As we can see in the figure, the results show the U-shaped relationship between the bank size and efficiency (convex curve). The turning points in the logarithmic form vary between 5.9005 and 6.0961, which is equivalent to EUR 1,247,564 thousand in the case of deposits and EUR 795,180 thousand in the case of loans. The value of the turning point suggests that in terms of this threshold, the growing bank size tends to decrease the efficiency, and beyond this threshold, the growing bank size tends to increase the efficiency of the analysed commercial banks.

When we analyse the relationship between the bank size and pure technical efficiency for each sub-period separately, we find out that the closet relationship was between the examined variables during the first sub-period, where the value of the R square was higher than 13%. During the second sub-period the relationship becomes weaker, and we can again see the reinforcement of the relationship between the variables within the last sub-period. The threshold value was approximately the same during each of the sub-periods. The U-shape, the relationship between variables, indicate that the smallest and largest banks in the sample tend to be the most efficient. It can also be seen according to the average value of the pure technical efficiency for the fifth percentile of smallest and largest banks in the sample. If we look at the situation from the point of view of total deposit, we can see that the fifth percentile of the smallest banks reached the average pure technical efficiency of 93.32%, the fifth percentile of the largest banks reached the average efficiency of 72.99%, while the rest of the sample reached the average efficiency of only 65.92%. If we look at the situation from the point of view of total loans, we can see that the fifth percentile of the smallest banks reached the average pure technical efficiency of 70.95%, the fifth percentile of the largest banks reached the average efficiency of 90.71%, while the rest of the sample reached average efficiency of only 66.17%. We can conclude that the most efficient were banks with the lowest values of deposits and the highest value of loans. It indicates that the most efficient were banks which were able to either transform their level of deposits to the highest level of loans, or which provide their level of loans from the lowest level of deposit. We can suppose that for the commercial bank it is more appropriate to choose the strategy of specialisation if it does not belong to the group of the largest banks in the market. From our analysis, the riskiest were medium-sized banks, suggesting that these banks should also be subject to regulatory oversight.

In the last part, we examine changes within individual sub-periods using the radial Malmquist index under the condition of constant return to scale. Table 4 records the results of this analysis.

The average progress of 46.37% in the total factor productivity is recorded in the first time window. The progress in the frontier technology positively determined this productivity growth of the analysed banks by 52.44% and a decline in the technical efficiency by 1.78%. In the second time window, we observe the Malmquist index (MI) indicating a slower improvement in the total factor productivity with an annual increase rate of 2.26%. This more gradual increase was supported by a decline in the innovation progress (which should be influenced by the financial crisis) by 9.21%, and even the positive catch-up effect (12.49%) could not tip the scales in the total factor productivity. In the third time window, the MI index recorded a 1.26% increase in the total factor productivity with growth in the relative technical efficiency (6.87%) and the adverse innovation effect (4.84%). The frontier shift effect representing the impact of innovation was positive only during the first sub-period. However, the source for this effect can be latent and of any type like technological change or progress, macroeconomic development central bank policies or even government regulations. All these issues, together with information technologies, influenced the banks' ability to offer more sophisticated products and services, enabling them to take their products closer to clients and so increase their efficiency. The catch-up effect was more critical during the second and third sub-periods, which represents an improvement in the technical efficiency due to improved operations and management of commercial banks and optimisation of the bank optimal size.

If we look at the results according to the countries shown in Table 5, we see that the average Malmquist index was above 1 in the Czech, Polish and Slovak banking sectors. This result shows a positive efficiency change in the mentioned banking sectors. The highest productivity growth was in Slovakia during the first sub-period which illustrated the most top performance change (an increase

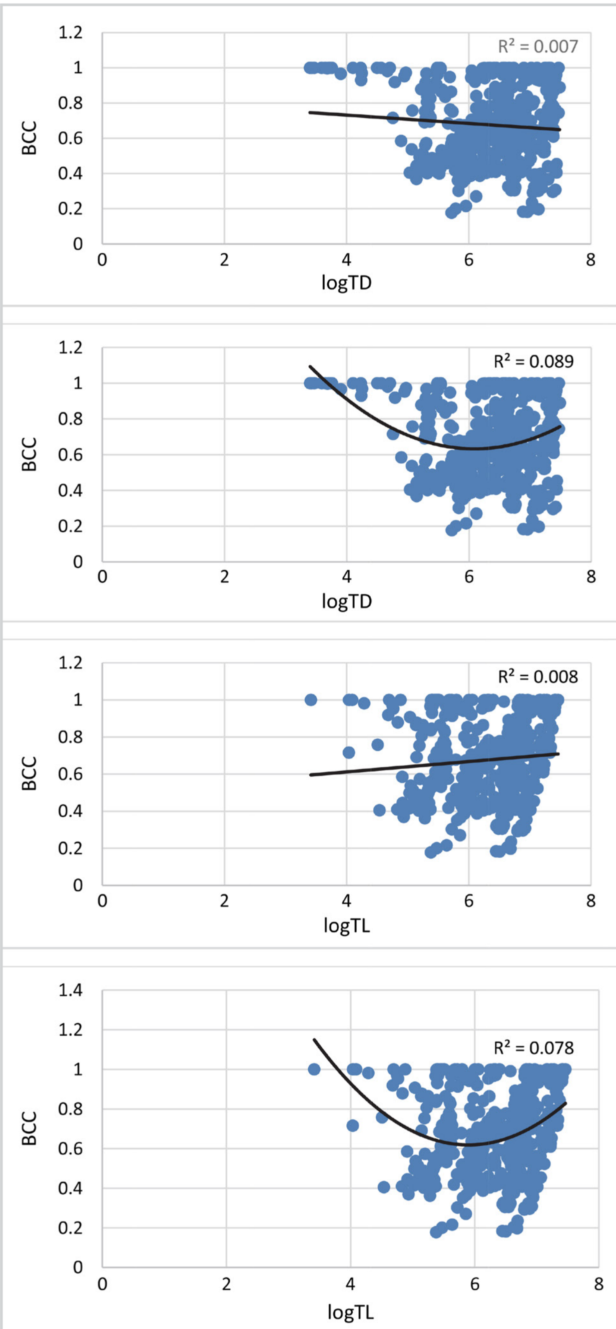

Fig. 3: **The relationship between the BCC efficiency and the bank size**

Source: Compiled by the authors

Tab. 4: **Productivity change indexes**

Years	Number of banks	Catch-up effect	Frontier-shift effect	Malmquist index
2005-2008	40	0.9822	1.5244	1.4637
2009-2012	40	1.1249	0.9079	1.0226
2013-2016	40	1.0687	0.9516	1.0126

Source: Compiled by the authors

Tab. 5: **Productivity change indexes in individual countries**

	Years	Number of banks	Catch-up effect	Frontier shift effect	Malmquist index
CR	2005-2008	11	0.9385	1.6204	1.4434
	2009-2012	11	1.2036	0.9181	1.1092
	2013-2016	11	1.0813	0.9582	1.0327
HU	2005-2008	12	0.9596	1.4159	1.3261
	2009-2012	12	0.9658	0.8906	0.8596
	2013-2016	12	0.9438	0.9511	0.8876
PL	2005-2008	6	1.0390	1.4331	1.4852
	2009-2012	6	1.2618	0.8980	1.1315
	2013-2016	6	1.1070	0.9420	1.0424
SR	2005-2008	11	1.0195	1.5966	1.6224
	2009-2012	11	1.1453	0.9223	1.0545
	2013-2016	11	1.1717	0.9506	1.1126

Source: Compiled by the authors

of 62.24%). Hungary reached the worst performance in the second sub-period, as its average Malmquist index was the lowest, indicating regress by 14.04%. The technological change achieved positive growth in all the countries only during the first sub-period. Therefore, we can suppose that the entrance of the Visegrad countries into the European Union had a positive impact on innovation which was developed, adapted or absorbed by players within the banking systems of all the states. The highest regress in the technological change can be seen in all the states during the second sub-period which was impacted during the crisis years. Therefore, the level of innovations was not so high as during the first sub-period. The regress in the technological change can also be seen in the last sub-period where the rate of decline is not so high. The difference in the technical efficiency in the form of the positive catch-up effect can be seen during all the sub-periods in the case of Poland and Slovakia. It indicates that the progress in the pure technical efficiency in these countries was primarily impacted by the growth in the efficiency change due to improved operations of management and the return to scale effect. Managers were able to manage the process of deposit-to-loan transformations more effectively, which led to an increase in their efficiency.

5. Conclusions

The aim of the article was to measure the technical efficiency in the Czech, Hungarian, Polish and Slovak banking sectors by using the non-parametric input-oriented DEA model with a constant and variable return to scale. We used the intermediation approach to define the input and output variables. The results bring the answer to the first research question: «Does the banking sector of the V4 countries perform efficiently?». We can see that the efficiency of the banking sector in the Visegrad countries increased during the analysed period except for the 2009-2011 period, when a slowdown was recorded due to the financial crisis and subsequent changes in the regulatory requirements or banks' loan assessment behaviour. The results showed that the banking sector in Hungary was the most efficient, followed by the Czech, Slovak and Polish banking sectors respectively.

The second research question was «What are the main sources of inefficiency, and is there any way how the managers of commercial banks can improve the efficiency of the transformation process in the V4 countries?» The identification of the factors of inefficiency may help to remove some barriers on the way to catch up with more efficient banks in the money lending business. The results showed that to improve efficiency it was required to reduce the value of inputs by 40% on average in the model with constant return to scale assumption, and by 22% in the model with a variable return to scale assumption. If we look at the reduction rates by country, we find that the highest reduction was required in the case of Polish banks in the model with constant return to scale assumption, and in the case of Slovak banks - in a model with a variable return to scale assumption.

When looking at the development of the whole banking industry according to the data published by the European Central bank, it can be seen that the volume of deposits slightly increased in Poland (9.5%), and Slovakia (5.2%) in 2017, while the number of employees decreased (by 4.6% in Slovakia and by 2.5% in Poland). This development is in line with the trends corresponding to the third sub-period. When considering the last analysed period (2013-2016), where the increase can be seen in the case of Poland (an increase in deposits - by 25%, loans - by 25% and the number of employees - by 2%) and Slovakia (an increase in deposits by 17%, loans - by 25% and the number of employees - by 4%), we can conclude that the development of the input variables is more positive, as the growth rate is slowing down with the current slowdown of loans (an increase by 11% in Slovakia and by 10% in Poland). Therefore, we can suppose that it will have a positive effect on the efficiency of the abovementioned banking sectors.

The analysis of the efficiency of the deposit-to-loan transformation process in the V4 countries has changed over the past years, which means that the relative technical efficiency changed during the three sub-periods. The CCR model recorded increasing median values of the overall technical efficiency during the three periods (38.48%, 45.29% and 54.83%). The BCC model showed more clustered results of the pure technical efficiency with the median increase of 16.56% between the first and second periods and an increase of 13.26% between the last two periods. The slowdown of the average technical efficiency in the second sub-period could be the result of the financial crisis in 2009. The comparison of the bank size and the pure technical efficiency showed the U-shaped relationship between the bank size and efficiency (the convex curve). The turning points vary between EUR 1,247,564 thousand in the case of deposits and EUR 795,180 thousand in the case of loans. The value of the turning point suggests that the growing bank size tends to decrease the efficiency within the threshold, whereas beyond this threshold the growing bank size tends to increase the efficiency of the analysed commercial banks.

Basing on the Malmquist index, it can be generally concluded that the frontier shift effect, representing the effect of innovation, was positive only during the first sub-period. During this sub-period, banks in the Visegrad countries increased their productivity mainly due to technological progress. The banking sector took advantages mostly of information technologies and reached a higher production frontier. During the second and third sub-periods, the catch-up effect was more critical, which represents an improvement in technical efficiency due to improved operations and management of commercial banks and also optimisation the bank size. The development of the innovation effect was slower than the increase in the relative efficiency, which can be caused by negative impacts relating to restrictive regulatory requirements, the 2008 financial crisis, and more gradual economic growth. The factors mentioned above can be considered to be the answer to our last research question: «What is the main reason for the positive/negative change in efficiency in the Visegrad countries?»

References

1. Adeleke, O. A., Adeleke, H. M., & Fajobi, D. O. (2017). Productivity Growth, Technical Progress, and Efficiency Change in ECOWAS Agriculture 1971-2009: A Full Cumulative (FC) Extended Malmquist Approach. *International Journal of Innovative Research and Advanced Studies, 4*(5), 416-423. Retrieved from http://www.ijiras.com/2017/Vol_4-Issue_5/paper_80.pdf
2. Asmild, M., Paradi, J. C., Aggarwall, V., & Schaffnit, C. (2004). Combining DEA Window Analysis with the Malmquist Index Approach in a Study of the Canadian Banking Industry. *Journal of Productivity Analysis, 21*(1), 67-89. doi: https://doi.org/10.1023/B:PROD.0000012453.91326.ec
3. Banker, R. D., Charnes, A., & Cooper, W. W. (1984). Some models for estimating technical and scale inefficiencies in Data Envelopment Analysis. *Management Science, 30*(9), 1078-1092. doi: https://doi.org/10.1287/mnsc.30.9.1078
4. Battese, G. E., Heshmati, A., & Hjalmarsson, L. (2000). Efficiency of labour use in the Swedish banking industry: a stochastic frontier approach. *Empirical Economics, 25*(4), 623-640. doi: https://doi.org/10.1007/s001810000037
5. Berg, S. A., Forsund, F. R., & Jansen, E. S. (1992). Malmquist indices of productivity growth during the deregulation of Norwegian banking, 1980-89. *The Scandinavian Journal of Economics, 94,* 211-228. Retrieved from https://ideas.repec.org/a/bla/scandj/v94y1992i0ps211-28.html
6. Boďa, M., & Zimková, E. (2015). Efficiency in the Slovak banking industry: a comparison of three approaches. *Prague Economic Papers, 24*(4), 434-451. doi: https://doi.org/10.18267/j.pep.546
7. Casu, B., & Molyneux, Ph. (2003). A comparative study of efficiency in European banking. *Applied Economics, 35*(17), 1865-1876. doi: https://doi.org/10.1080/0003684032000158109
8. Casu, B., Ferrari, A., Girardone, C., & Wilson, J. O. S. (2016). Integration, productivity and technological spillovers: Evidence for eurozone banking industries. *European Journal of Operational Research, 255*(3), 971-983. doi: https://doi.org/10.1016/j.ejor.2016.06.007
9. Casu, B., Girardone, C., & Molyneux, Ph. (2004). Productivity change in European banking: a comparison of parametric and non-parametric approaches. *Journal of Banking & Finance, 28*(10), 2521-2540. doi: https://doi.org/10.1016/j.jbankfin.2003.10.014
10. Černohorská, L., Pilyavskyy, A., & Aaronson, W. (2017). Comparative performance of the Visegrad group banks for the period 2009-2013. *E+M Ekonomie a Management, 20*(2), 175-187. doi: https://doi.org/10.15240/tul/001/2017-2-013
11. Charnes, A., Clark, T. C., Cooper, W. W., & Golany, B. (1985). A developmental study of data envelopment analysis in measuring the efficiency of maintenance units in U.S. air forces. *Annals of Operational Research, 2*(1), 95-112. doi: https://doi.org/10.1007/BF01874734
12. Charnes, A., Cooper, W. W., & Rhodes, E. (1978). Measuring the efficiency of decision-making units. *European Journal of Operational Research, 2*(6), 429-444. doi: https://doi.org/10.1016/0377-2217(78)90138-8
13. Charnes, A., Cooper, W. W., Lewin, A. Y., & Seiford, L. M. (1995). *Data Envelopment Analysis: Theory, Methodology and Applications.* New York: Springer-Verla.
14. Cooper, W. W., Seiford L. M., & Tone, K. (2007). *Data Envelopment Analysis: A comprehensive text with models applications.* New York: Springer Science.
15. Cooper, W. W., Seiford, L. M., & Zhu, J. (2011). *Handbook on Data Envelopment Analysis.* New York: Springer Science. doi: https://doi.org/10.1007/978-1-4419-6151-8
16. Degl'Innocenti, M., Kourtzidis, S. A., Sevic, Z., & Tzeremes, N. G. (2017). Bank productivity growth and convergence in the European Union during the financial crisis. *Journal of Banking & Finance, 75,* 184-199. doi: https://doi.org/10.1016/j.jbankfin.2016.11.016
17. Färe, R., Grosskopf, S., Lindgren, B., & Roos, P. (1994). Productivity developments in Swedish hospitals: a Malmquist output index approach. In A. Charnes, W. W. Cooper, A. Y. Lewin & L. M. Seiford (Eds). *Data envelopment analysis: theory, methodology, and applications* (pp. 253-272). Springer. doi: https://doi.org/10.1007/978-94-011-0637-5
18. Jablonský, J. (2012). Multicriteria approaches for ranking of efficient units in DEA models. *Central European Journal of Operational Research, 20*(3), 435-449. doi: https://doi.org/10.1007/s10100-011-0223-6
19. Kiseľáková, D., & Kiseľák, A. (2013). Analysis of banking business and its impact on financial stability of economies in Euro area. *Polish Journal of Management Studies, 8,* 121-131. Retrieved from http://oaji.net/articles/2014/1384-1416475837.pdf
20. Kumbhakar, S. C., Lozano-Vivas, A., Lovell, C. A. K., & Hassan, I. (2001). The effects of deregulation on the performance of financial institutions: the case of Spanish savings banks. *Journal of Money, Credit and Banking, 33*(1), 101-120. doi: https://doi.org/10.2307/2673874
21. Martinez-Miera, D., & Repullo, R. (2010). Does competition reduce the risk of bank failure? *The Review of Financial Studies, 23*(10), 3638-3664. doi: https://doi.org/10.1093/rfs/hhq057
22. Palečková, I. (2015). Estimation of the efficiency of Slovak commercial banks by the Data Envelopment Analysis. *Acta Academica Karvinensia, 1,* 130-140. Retrieved from http://aak.slu.cz/pdfs/aak/2015/01/11.pdf
23. Palečková, I. (2017). Efficiency change of banking sectors and banks in the financial conglomerates in Visegrad group countries. *Ekonomický časopis, 65*(1), 79-92. Retrieved from https://www.researchgate.net/publication/316605666_Efficiency_Change_of_Banking_Sectors_and_Banks_in_the_Financial_Conglomerates_in_Visegrad_Group_Countries
24. Pastor, J.-M., Perez, F., & Quesada, J. (1997). Efficiency analysis in banking firms: An international comparison. *European Journal of Operational Research, 98*(2), 395-407. doi: https://doi.org/10.1016/S0377-2217(96)00355-4
25. Pitoňáková, R. (2015). Determinants of household saving: Evidence from Slovakia. *Ekonomický časopis, 63*(8), 837-852. Retrieved from https://www.researchgate.net/publication/301713519_Determinants_of_Household_Saving_Evidence_from_Slovakia
26. Ponomarenko, V., Kolodiziev, O., & Chmutova, I. (2017). Benchmarking of bank performance using the life cycle concept and the DEA approach. *Banks and Bank Systems, 12*(3), 74-86. doi: https://doi.org/10.21511/bbs.12(3).2017.06
27. Řepková, I. (2014). Efficiency of the Czech banking sector employing the DEA window analysis approach. *Procedia Economics and Finance, 12,* 587-596. doi: https://doi.org/10.1016/S2212-5671(14)00383-9
28. Shepherd, R. W. (1953). *Cost and Production Functions.* Princeton: Princeton University Press.
29. Sherman, H. D., & Gold, F. (1985). Bank branch operating efficiency: Evaluation with Data Envelopment Analysis. *Journal of Banking and Finance, 9*(2), 297-315. doi: https://doi.org/10.1016/0378-4266(85)90025-1
30. Toloo, M., Allahyar, M., & Hančlová, J. (2018). A non-radial directional distance method on classifying inputs and outputs in DEA: application to banking industry. *Expert Systems with Applications, 92,* 495-506. doi: https://doi.org/10.1016/j.eswa.2017.09.034
31. Zimková, E. (2014). Technical efficiency and super-efficiency of the banking sector in Slovakia. *Procedia Economics and Finance, 12,* 780-787. doi: https://doi.org/10.1016/S2212-5671(14)00405-5

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