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ASSESSING BANK EFFICIENCY WITH THE USE OF DEA METHOD: INTEGRATING INTELLECTUAL CAPITAL INTO THE EVALUATIVE FRAMEWORK

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Abstract. Nowadays, banks play a key role in economic development and in ensuring the stability of the financial system; therefore, it is crucial to identify the factors that influence the efficiency of their operations. In the literature, this issue is analysed from two main perspectives: the bank as a producer and the bank as a financial intermediary. In the era of digitalisation and globalisation, competitiveness is no longer based solely on asset size or the growth of basic financial indicators, but rather on the ability to create and utilise intangible resources (intellectual capital). The research aims to assess the efficiency level of banks operating in Poland using two approaches: the traditional production-based efficiency approach and a modern approach based on intellectual capital. The research employs the non-parametric Data Envelopment Analysis (DEA) method, a widely used approach in banking efficiency research. The research sample consists of 10 listed banks on the Warsaw Stock Exchange (WSE), ensuring access to consistent and comparable financial and non-financial data. The selection of this group is based on their significant role in the Polish banking sector and their importance in the sector's transformation processes. The authors test the research hypothesis that the efficiency level of banks operating in Poland differs depending on the adopted evaluation approach — traditional (production-based) or modern, based on intellectual capital. Including intangible resources in the efficiency analysis significantly alters the classification of banks based on their performance. The study period covers the years 2015–2024.

Keywords: bank efficiency; DEA; intellectual capital; producer approach

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1. Introduction

The contemporary banking sector operates in an environment of intense competition, dynamic technological change, and increasing regulatory and market pressures. Processes of globalisation, digitalisation, and the transformation of business models mean that banks are increasingly competing not only in terms of financial capital, but above all through their ability to effectively utilise intangible resources such as knowledge, innovation, and stakeholder relationships (Rosińska-Bukowska, 2022; Khanal, 2023).

The modern financial sector is undergoing rapid technological transformation — automation, data analytics, artificial intelligence (AI), and digital solutions are gaining importance. In banking, electronic and mobile banking systems play a particularly significant role, as they not only enhance operational efficiency but also improve the quality and speed of customer service, thereby shaping the overall customer experience. These

solutions allow banks to personalise services, manage risks more effectively, and adapt more rapidly to changing market conditions.

The literature emphasises that banking efficiency has become a key determinant of competitiveness, stability, and the ability to create added value in the economy (Klepczarek et al., 2024; Pitre-Cedeño & Herrera-Rodríguez, 2024). Traditionally, the competitiveness of banks was associated mainly with financial factors such as profitability, asset size, market share, or operating costs. Increasingly, however, non-financial factors — those that make up a bank's intellectual capital — are recognised as crucial sources of competitive advantage (Rehman et al., 2022; Rong et al., 2025).

Intellectual capital (IC), understood as a strategic organisational resource, determines the capacity of financial institutions to innovate, adapt to a changing environment, and achieve long-term growth (Le, 2022). It is increasingly recognised as one of the key drivers of competitive advantage in 21st-century banking (Rosińska-Bukowska, 2022; Ullah et al., 2023; Anielak-Sobczak, 2023; Pitre-Cedeño & Herrera-Rodríguez, 2024). Knowledge resources, employee competencies, customer relationships, and internal process efficiency directly affect productivity, service quality, and operational effectiveness. Banks that effectively manage these resources are better equipped to build sustainable competitive positions and respond to digitalisation and cost pressures (Rong et al., 2025).

In this article, a bank's intellectual capital is understood as a resource rooted in the knowledge, skills, and competencies of its employees, as well as in the network of relationships with key stakeholders, including clients, business partners, market competitors, regulators, and shareholders. It shapes a structure of interconnections encompassing organisational processes, innovation activities, and relations with both the internal and external environment of the financial institution. Intellectual capital consists of three interrelated components: organisational capital, which determines the efficiency of internal structures and processes; innovation capital, linked to the ability to develop and implement new technological, product, and process solutions; and relational capital, based on the quality and strength of stakeholder relations (Rosińska-Bukowska, 2022; Rong et al., 2025).

In empirical research, the efficiency of banks is most often assessed using traditional financial indicators such as total assets, equity, the volume of loans and deposits, profitability measures (ROA, ROE), or cost-to-income ratio (CIR). Data Envelopment Analysis (DEA) is one of the most widely used tools in this field, as it enables the evaluation of the relative technical efficiency of decision-making units (DMUs), taking into account multiple inputs and outputs simultaneously, without the need to define a production function *ex ante* (Khanal, 2023; Delahoz-Domínguez et al., 2024; Klepczarek et al., 2024).

However, most existing studies focus primarily on complex, measurable financial data while overlooking or marginalising intangible resources. They do not account for strategic sources of competitive advantage such as technological innovation, stakeholder relations, ESG, or reputation (Rehman et al., 2022; Rong et al., 2025). For this reason, the literature increasingly calls for extending DEA models to include non-financial variables related to intellectual capital, including innovation, organisational, and infrastructural components.

To date, there remains a lack of extensive research combining traditional DEA efficiency measurements with the dimension of intellectual capital, representing a significant research gap. This study therefore proposes to go beyond conventional financial indicators and incorporate those reflecting the intellectual potential of banks, such as: innovation component (digital technologies, digitalisation, number of mobile and online banking users, AI adoption), relational component (brand image, ESG performance, quality rankings), organisational component (number of employees, branches, wage levels).

Such an approach enables a more comprehensive assessment of the ability of financial institutions to create value and compete in the market, by linking classical technical efficiency with intangible determinants of competitiveness.

In view of the above, the current objective of this study is to assess the efficiency level of banks operating in Poland using two approaches: the traditional production-based efficiency approach and a modern approach based on intellectual capital. In the article, there was a verified research hypothesis that the efficiency level of banks operating in Poland differs depending on the adopted measurement approach — traditional (intermediary-based and production-based) versus an approach that incorporates intangible factors (intellectual capital).

2. Bank Efficiency – Traditional and Intellectual Capital–Based Approaches

Bank efficiency has long been a key issue in financial sector research. In the classical approach, it was defined mainly in financial and technical terms, which translated into the widespread use of profitability and productivity indicators. Among the most commonly used measures are ROA (Return on Assets), ROE (Return on Equity), the CIR ratio (Cost-to-Income Ratio), and NIM (Net Interest Margin). These indicators enable the measurement of the economic and cost efficiency of banks in relation to the resources utilised (Delahoz-Domínguez et al., 2024; Klepczarek et al., 2024).

Empirical studies have traditionally relied on intermediation and production models. In the intermediation approach, the bank is viewed as a financial intermediary transforming deposits into loans. Inputs typically include operating costs and the value of deposits, while outputs comprise loan values, net financial results, and interest income. In the production approach, the bank is viewed as a producer of financial services, with outputs including deposits, loans, and fee-based income. The most frequently applied efficiency measurement methods in these studies are DEA (Data Envelopment Analysis) and SFA (Stochastic Frontier Analysis), which allow for the estimation of the relative efficiency of decision-making units without the need to specify a production function *ex ante* (Pitre-Cedeño & Herrera-Rodríguez, 2024).

In recent years, however, there has been a marked shift in the research perspective—from narrowly defined financial efficiency toward a strategic approach that incorporates intangible factors and intellectual capital (IC). Le et al. (2022), in a study of 26 commercial banks in Vietnam from 2007 to 2019, demonstrated that intellectual capital components, such as human capital (HC) and structural capital (SC), have a significant impact on bank efficiency, as measured using DEA. Notably, banks with higher HC levels achieved higher ROA and ROE ratios even when their asset levels were comparable.

Similarly, Rehman et al. (2022), analysing the banking sector in Pakistan, confirmed a positive relationship between intellectual capital efficiency (measured using the VAIC index) and banks' financial performance. The most substantial effects were observed for CEE (Capital Employed Efficiency) and HCE (Human Capital Efficiency), highlighting that the management of human resources and financial capital is a key source of competitive advantage for financial institutions. Likewise, Zheng et al. (2022) demonstrated that IC affects not only efficiency but also banks' risk profiles; institutions with higher IC levels exhibited greater resilience to external shocks and improved financial stability. In European research, Rong et al. (2025) applied an extended DEA model that included both financial indicators and IC components. Their findings revealed that incorporating variables such as the number of digital banking users, technological investment, and ESG indicators yields significantly different efficiency assessments compared to traditional models. Banks with strong relational and innovation capital achieved higher efficiency scores despite having smaller financial assets.

These findings confirm that bank efficiency is multidimensional, and financial indicators alone reflect only part of an institution's true potential. Increasingly, efficiency is understood as the capacity for technological adaptation, knowledge management, and building stakeholder relationships. In practice, this means a shift away from static efficiency measurement toward dynamic models that allow researchers to analyse not only the level of efficiency but also the pace of its change over time. One example is the use of the Malmquist Index, applied by Delahoz-Domínguez et al. (2024) to assess efficiency dynamics in the Latin American banking sector.

Modern research, therefore, confirms that an effective assessment of bank efficiency requires the integration of traditional financial indicators (ROA, ROE, CIR, NIM) with qualitative factors (HCE, SCE, CEE, digitisation and ESG indicators), emphasising the growing importance of intangible measures. This approach provides a

more accurate reflection of the real ability of financial institutions to compete and adapt in a globally transforming digital environment.

3. DEA Method - Theoretical Basis

In the literature on the subject, the DEA method is used to determine the efficiency of banking sectors or banks from a given group. The efficiency indicator calculated using this method is relative efficiency (Gulati et al., 2023; Istaiteyeh et al., 2024). The DMU group under research may include similar entities capable of transforming inputs into outputs (Hsiung et al., 2025). The results obtained by DMU are compared to the results of the other DMUs (Shaik, 2022). In this way, it is possible to rank the efficiency of DMUs for the research group (Patra et al., 2023). Efficiency calculated using the DEA method takes values from the range [0, 1], with DMUs with an efficiency index of 1 being defined as efficient (Berhe, 2025). In the DEA method, more than one DMU can be efficient. This does not mean that efficient DMUs have the same input and output values or that they use the same solutions (Hasannasab et al., 2024). Some efficient DMUs can serve as benchmarks for inefficient DMUs (Cui et al., 2025).

The literature on the subject categorises DEA models based on economies of scale and input or output orientation. The first criterion is the orientation of the model, which may aim to maximise outputs or minimise inputs (Demircioğlu & Özgüner, 2022). It is also possible to use a model without orientation. Approaches to economies of scale include models with constant economies of scale (CCR model) (Flores-Ureba et al., 2024) and models with variable economies of scale (BCC model, models with non-increasing economies of scale, models with increasing economies of scale, models with non-decreasing economies of scale (Kosmaczewska, 2011). This division is supplemented by the definition of efficiency as radial (referring to all examined inputs or all examined outputs) or non-radial (in an input-oriented model, it is examined separately for each of the inputs included in the research, while in an output-oriented model, efficiency is examined separately for each of the outputs included in the research) (Wolszczak-Derlacz, 2013).

The literature on the subject describes many models of the DEA method. The CCR model is the first DEA model. It was developed by Charnes, Cooper, and Rhodes. The authors of the first DEA model proposed using a weighted sum of inputs and a weighted sum of outputs to calculate efficiency (Amirteimoori, 2025). In the CCR model, the efficiency indicators for the input-oriented model and the output-oriented model are inverses of each other. This model assumes constant returns to scale. Efficiency in this DEA model can be defined as follows (Baran, 2007):

$$Efficiency(\theta) = \frac{\sum_{r=1}^m \mu_r Output_r}{\sum_{i=1}^n v_i Input_i}$$

where:

m - number of outputs,

n - number of inputs,

μ_r - the intensity of individual outputs,

v_i - the relative importance of individual inputs.

Another DEA model is the BCC model (named after its authors: Banker, Charnes and Cooper), which is an extension of the CCR model that takes into account variable economies of scale (Fonseka & Al Farooque, 2024). This means that researchers using the BCC model assume that DMUs are affected by market events that are beyond their control and may cause economies or diseconomies of scale. The BCC model takes variable economies of scale into account, but does not specify what type they are. In the BCC model, the efficiency indicators for the input-oriented model and the output-oriented model are not inverses of each other. The literature recommends using this model to measure the efficiency of developed banking sectors or banks operating within them (Titko, Stankeviciene, & Lace, 2014). Efficiency in the DEA method is determined using an objective function (θ), in which weights act as decision variables. The optimal objective function is inherently linked to the determination of weights (μ_r ; v_i). These weights enable the determination of a set of benchmarks (so-called reference objects). This makes it possible to determine to what extent a given entity

should reduce its inputs while maintaining the level of outputs (input-oriented DEA) or increase outputs at the current level of inputs (output-oriented DEA) (Masternak-Janus & Rybaczewska-Błażejowska, 2016).

4. Methodology and Course of the Research

The research included banks listed on the Warsaw Stock Exchange (Alior Bank, BNP Paribas, mBank, Citi Handlowy, ING Bank, Millenium Bank, PEKAO Bank, PKO BP, Santander Bank, BOŚ). The research period spanned from 2015 (the year mobile banking users began to be reported; earlier data do not cover the entire group) to 2024 (the latest available data). The research was conducted using a non-radial BCC model focused on expenditure. The choice of model was due to the specific nature of the group of entities under research, which is influenced by factors outside the Polish banking sector. On the other hand, the use of an input-oriented model made it possible to identify entities that were effective with the inputs used. The research compared two approaches to bank efficiency. The first, referred to as traditional, was an approach to bank efficiency understood as a producer. The second approach involved assessing bank efficiency in terms of its intellectual capital.

After examining simple statistical methods and correlations, the research took into account:

- inputs: Operating costs, Equity, Number of bank branches,
- outputs: Loans, Deposits, Net profit.

After examining simple statistical methods and correlations, the research took into account:

- inputs: Operating costs, Training costs, Number of bank branches, Employee benefits/number of employees,
- outputs: Złoty Bankier – measure, Number of clients actively using online banking/number of clients.

The research of the efficiency of banks listed on the Warsaw Stock Exchange was divided into three stages. The first stage involved determining the average efficiency of banks in terms of the bank as a producer and efficiency indicators in terms of individual inputs. The second stage involved determining the efficiency of banks in terms of intellectual capital and efficiency indicators in terms of individual inputs. In the third stage, the results indicate which banks were effective in particular approaches, and whether there were similar groups of efficient banks in both approaches.

5. Results

Tables 1 and 2 present the results of the efficiency analysis of banks listed on the Warsaw Stock Exchange in the years 2015-2024, using an approach that considers the bank as a producer. Table 1 shows the results of non-radial efficiency, i.e., the average obtained from efficiency based on individual inputs. Further, Table 2 presents the results of efficiency coefficients for individual inputs, allowing for the identification of which inputs contributed to the inefficiency of certain entities.

Table 1. Summary of the results of the research on the effectiveness of banks operating on the Warsaw Stock Exchange from the perspective of the bank as a producer

Bank	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Alior Bank	1,00	1,00	1,00	1,00	1,00	1,00	1,00	0,71	0,76	1,00
BNP Paribas	1,00	1,00	0,81	1,00	0,58	1,00	0,63	0,60	0,63	0,62
mBank	0,66	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
Citi Handlowy	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
ING Bank	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
Millenium Bank	0,73	1,00	1,00	0,77	1,00	1,00	1,00	1,00	1,00	1,00
PEKAO Bank	1,00	1,00	1,00	0,75	0,90	0,67	0,76	0,63	1,00	1,00
PKO BP	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
Santander Bank	1,00	1,00	1,00	1,00	0,94	1,00	0,67	1,00	0,76	1,00
BOŚ	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00

Source: Based on research conducted by the authors in the R computing environment using the *deaR* package, with data from financial statements of the examined banks, reports on the activities of the management boards of the examined banks, NetB@nk Reports on online and mobile banking, cashless payments for the years 2015-2024

At the end of each year from 2015 to 2024, Citi Handlowy, ING Bank, PKO BP, and BOŚ were effective in the producer bank approach. Each of the banks researched was effective in at least one of the years researched. Banks that achieved an efficiency of less than 0.7 in at least two years of the period researched were considered the least effective in the period researched. These were BNP Paribas (2019, 2021, 2022, 2023, 2024) and PEKAO Bank (2020, 2022). This means that the expenditures incurred by these banks in some years were too high in relation to the results achieved. Table 2 below presents the efficiency results of the entities researched in terms of individual expenditures.

Table 2. Summary of the results of the research on the effectiveness of banks operating on the Warsaw Stock Exchange in the bank as a producer approach in terms of individual expenditures

Bank	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Efficiency in terms of Operating Costs										
Alior Bank	1,00	1,00	1,00	1,00	1,00	1,00	1,00	0,73	0,70	1,00
BNP Paribas	1,00	1,00	0,95	1,00	0,45	1,00	0,80	0,84	0,70	0,82
mBank	0,53	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
Citi Handlowy	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
ING Bank	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
Millenium Bank	0,57	1,00	1,00	0,84	1,00	1,00	1,00	1,00	1,00	1,00
PEKAO Bank	1,00	1,00	1,00	0,69	0,99	0,99	0,86	0,71	1,00	1,00
PKO BP	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
Santander Bank	1,00	1,00	1,00	1,00	1,00	1,00	0,68	1,00	0,94	1,00
BOŚ	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
Efficiency in terms of Equity										
Alior Bank	1,00	1,00	1,00	1,00	1,00	1,00	1,00	0,73	0,94	1,00
BNP Paribas	1,00	1,00	1,00	1,00	1,00	1,00	0,72	0,61	0,81	0,70
mBank	0,54	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
Citi Handlowy	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
ING Bank	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
Millenium Bank	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
PEKAO Bank	1,00	1,00	1,00	0,92	0,97	0,63	0,78	0,56	1,00	1,00
PKO BP	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
Santander Bank	1,00	1,00	1,00	1,00	0,87	1,00	0,62	1,00	0,61	1,00
BOŚ	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
Efficiency in terms of the Number of Bank Branches										
Alior Bank	1,00	1,00	1,00	1,00	1,00	1,00	1,00	0,68	0,63	1,00
BNP Paribas	1,00	1,00	0,47	1,00	0,29	1,00	0,37	0,36	0,37	0,33
mBank	0,92	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
Citi Handlowy	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
ING Bank	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
Millenium Bank	0,62	1,00	1,00	0,47	1,00	1,00	1,00	1,00	1,00	1,00
PEKAO Bank	1,00	1,00	1,00	0,65	0,73	0,39	0,65	0,61	1,00	1,00
PKO BP	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
Santander Bank	1,00	1,00	1,00	1,00	0,95	1,00	0,70	1,00	0,73	1,00
BOŚ	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00

Source: Based on research conducted by the authors in the R computing environment using the deaR package, with data from financial statements of the examined banks, reports on the activities of the management boards of the examined banks, NetB@nk Reports on online and mobile banking, cashless payments for the years 2015-2024

The above information enables the identification of which expenditures contributed to the inefficiency of individual banks. Considering the expenditures incurred in the research, the number of bank branches was the primary cause of inefficiency among the entities examined. The second expenditure that did not turn into the expected results was operating costs. Due to this expenditure, the efficiency ratios for the entities researched in individual years from 2015 to 2024 were not on the efficiency curve in 45 cases (across different entities and years within the research period). Tables 3 and 4 below present the results of the efficiency research on banks listed on the Warsaw Stock Exchange from 2015 to 2024, using an approach that takes intellectual capital into account.

Table 3. Summary of the results of the research on the effectiveness of banks operating on the Warsaw Stock Exchange, taking into account intellectual capital

Bank	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Alior Bank	1,00	0,84	0,38	1,00	1,00	1,00	1,00	1,00	1,00	1,00
BNP Paribas	1,00	1,00	1,00	1,00	0,62	0,71	0,63	0,63	0,60	0,57
mBank	1,00	1,00	1,00	1,00	1,00	1,00	1,00	0,68	1,00	1,00
Citi Handlowy	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
ING Bank	1,00	1,00	1,00	0,76	1,00	1,00	1,00	1,00	1,00	1,00
Millenium Bank	0,81	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
PEKAO Bank	0,34	0,31	0,33	0,56	0,53	0,40	0,48	0,50	0,43	0,42
PKO BP	1,00	1,00	1,00	1,00	1,00	1,00	0,48	0,57	1,00	1,00
Santander Bank	0,59	0,46	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
BOŚ	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00

Source: Based on research conducted by the authors in the R computing environment using the deaR package, with data from financial statements of the examined banks, reports on the activities of the management boards of the examined banks, NetB@nk Reports on online and mobile banking, cashless payments for the years 2015-2024

At the end of each year from 2015 to 2024, Citi Handlowy and BOŚ were included in the efficiency approach, taking into account intellectual capital. Each of the banks researched was efficient in at least one of the years studied. As in the case of the producer bank approach, it was assumed that inefficient banks were those that achieved an efficiency below 0.7 in at least two years of the researched period. These were BNP Paribas (2019, 2021, 2022, 2023, 2024) and PEKAO Bank (years from the period 2015-2024). This means that the expenditures incurred by BNP Paribas in some years were too high in relation to the achieved results. In the case of PEKAO Bank, the effects achieved were much lower in relation to the expenditures incurred. Table 4 presents the components of the non-radial efficiency coefficient, i.e., efficiency coefficients in relation to individual expenditures.

Table 4. Summary of the results of the efficiency research of banks operating on the WSE, taking into account intellectual capital in relation to individual expenditures

Bank	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Efficiency in terms of Operating Costs										
Alior Bank	1,00	0,77	0,14	1,00	1,00	1,00	1,00	1,00	1,00	1,00
BNP Paribas	1,00	1,00	1,00	1,00	0,54	0,76	0,62	0,72	0,50	0,45
mBank	1,00	1,00	1,00	1,00	1,00	1,00	1,00	0,48	1,00	1,00
Citi Handlowy	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
ING Bank	1,00	1,00	1,00	0,55	1,00	1,00	1,00	1,00	1,00	1,00
Millenium Bank	0,84	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
PEKAO Bank	0,10	0,03	0,27	0,37	0,33	0,23	0,31	0,29	0,20	0,18
PKO BP	1,00	1,00	1,00	1,00	1,00	1,00	0,24	0,29	1,00	1,00
Santander Bank	0,45	0,38	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
BOŚ	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
Efficiency in terms of Training Costs										
Alior Bank	1,00	0,62	0,20	1,00	1,00	1,00	1,00	1,00	1,00	1,00
BNP Paribas	1,00	1,00	1,00	1,00	0,38	0,62	0,20	0,17	0,37	0,27
mBank	1,00	1,00	1,00	1,00	1,00	1,00	1,00	0,51	1,00	1,00
Citi Handlowy	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
ING Bank	1,00	1,00	1,00	0,63	1,00	1,00	1,00	1,00	1,00	1,00
Millenium Bank	0,68	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
PEKAO Bank	0,10	0,14	0,14	0,44	0,39	0,41	0,23	0,24	0,14	0,27
PKO BP	1,00	1,00	1,00	1,00	1,00	1,00	0,29	0,84	1,00	1,00
Santander Bank	0,61	0,22	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
BOŚ	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
Efficiency in terms of the Number of Bank Branches										
Alior Bank	1,00	0,96	0,34	1,00	1,00	1,00	1,00	1,00	1,00	1,00
BNP Paribas	1,00	1,00	1,00	1,00	0,89	0,63	0,83	0,94	0,54	0,58
mBank	1,00	1,00	1,00	1,00	1,00	1,00	1,00	0,90	1,00	1,00

Citi Handlowy	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
ING Bank	1,00	1,00	1,00	0,96	1,00	1,00	1,00	1,00	1,00	1,00
Millenium Bank	0,72	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
PEKAO Bank	0,17	0,11	0,11	0,45	0,72	0,34	0,61	0,62	0,39	0,38
PKO BP	1,00	1,00	1,00	1,00	1,00	1,00	0,41	0,19	1,00	1,00
Santander Bank	0,33	0,35	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
BOS	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
Efficiency in terms of Relation between Employee Benefits and the Number of Bank Employees										
Alior Bank	1,00	1,00	0,83	1,00	1,00	1,00	1,00	1,00	1,00	1,00
BNP Paribas	1,00	1,00	1,00	1,00	0,67	0,82	0,86	0,69	0,97	0,97
mBank	1,00	1,00	1,00	1,00	1,00	1,00	1,00	0,82	1,00	1,00
Citi Handlowy	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
ING Bank	1,00	1,00	1,00	0,90	1,00	1,00	1,00	1,00	1,00	1,00
Millenium Bank	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
PEKAO Bank	0,97	0,97	0,79	1,00	0,66	0,62	0,78	0,85	0,97	0,83
PKO BP	1,00	1,00	1,00	1,00	1,00	1,00	0,96	0,96	1,00	1,00
Santander Bank	0,98	0,87	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
BOS	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00

Source: Based on research conducted by the authors in the R computing environment using the deaR package, with data from financial statements of the examined banks, reports on the activities of the management boards of the examined banks, NetB@nk Reports on online and mobile banking, cashless payments for the years 2015-2024

Table 4 contains efficiency coefficients for individual expenditures, allowing for the identification of which expenditures contributed to the inefficiency of certain entities. Taking into account the expenditures included in the research, training costs were the primary cause of inefficiency among the entities researched. The second expenditure that did not translate into the expected results was operating costs.

During the research period, some banks were effective in each of the approaches to effectiveness adopted. In the first year of the research period, the groups of effective entities were almost the same – PEKAO Bank and Santander Bank were effective in the producer bank approach, but ineffective when intellectual capital was taken into account. At the same time, mBank was ineffective in the producer bank approach and effective in the second approach. In 2016, three entities (Alior Bank, PEKAO Bank, Santander Bank) were effective in the producer bank approach, but were not effective in the second approach. In subsequent years of the period under review, the efficiency ratios in the individual approaches to bank efficiency differed in the results achieved by one or two entities. In both approaches, BNP Paribas and PEKAO Bank were inefficient in several years of the research period.

6. Discussion

The findings of this research indicate that incorporating intellectual capital into efficiency assessment models significantly alters the results of DMUs efficiency compared with models based solely on traditional financial indicators. This outcome confirms the growing importance of intangible resources in the banking sector. It simultaneously distinguishes the present research from the existing literature, where DEA analyses predominantly rely on financial data and conventional production-based approaches. In Polish research, such as Mastalerz (2017) and Czerwonka (2019), efficiency assessments rely exclusively on financial variables—assets, deposits, operating costs and loan volumes—without accounting for intellectual capital as a productive input. Similarly, international studies employ classical financial sets of DEA variables: Turkish analyses apply CAMELS indicators (Wang et al., 2024), Serbian studies utilise the intermediation, operating and profitability approaches (Horvat et al., 2022), while a pan-European analysis of 471 banks relies on ROA, capitalisation, liquidity and provisioning measures (Licerán-Gutiérrez et al., 2025).

Asian studies also predominantly focus on financial metrics. Malaysian banks are evaluated using the SE-SBM model with inputs such as deposits, assets and equity, and non-interest income and investment as outputs (Kasim et al., 2019). Chinese studies adopt an extended by-production SBM framework that incorporates undesirable outputs such as non-performing loans (Shi et al., 2023). None of these approaches integrate

components of intellectual capital. The only research explicitly addressing intellectual capital—conducted on Nigerian listed banks (Olohunlana et al., 2023)—evaluates IC efficiency exclusively, without comparing it against financial efficiency or applying a dual-perspective framework. The present research addresses this gap by adopting a two-track efficiency approach with the use of DEA, which separately assesses financial efficiency and intellectual capital efficiency, enabling the identification of divergences between the two dimensions and demonstrating that banks performing well in traditional DEA models may not necessarily excel in managing intangible resources.

The distinctiveness of this research becomes even more pronounced when juxtaposed with recent analyses on the condition and competitiveness of the banking sector. The study by Iwanicz-Drozowska and Nowak (2024) examines the competitiveness of the Polish banking sector relative to EU members between 2004 and 2022, focusing on financial indicators such as ROE, net interest margin, cost-to-income ratio, capital adequacy and sector concentration measures. Although the authors highlight the rising role of digitalisation and technological advancements in shaping bank competitiveness, their research neither applies DEA methodology nor integrates intangible resources into the analytical framework. This reinforces the importance of the present research's approach: intellectual capital—comprising knowledge, innovation, organisational capabilities, and customer relations—has become a strategic determinant of contemporary banking performance and should be explicitly incorporated into efficiency models.

The temporal and contextual scope further differentiates this research from prior research. While international studies mainly cover pre-pandemic periods (e.g., Malaysia 2004–2013; Serbia 2008–2019; Poland 2013–2018), the present analysis spans 2015–2024—a period marked by intense digital transformation, the COVID-19 pandemic and dynamic regulatory and technological shifts. Additionally, whereas most earlier studies examine sectoral or aggregated banking performance, the present research focuses on individual publicly listed banks and applies a richer set of inputs and outputs, including non-financial, intangible variables.

In summary, this research adds significant value to the literature by demonstrating that traditional use of DEA models—relying exclusively on financial measures—does not fully capture the organisational and innovative capabilities of modern banks. Integrating intellectual capital into an efficiency approach reveals alternative sources of competitive advantage and provides a better explanation of heterogeneity in bank performance in increasingly digitalised environments. The simultaneous application of financial DEA and IC-DEA constitutes a novel methodological and empirical contribution that clearly differentiates this research from prior national and international studies, underscoring its innovative character.

Conclusions

The findings of this research indicate that incorporating intellectual capital into efficiency assessment models significantly alters the results of DMUs efficiency compared with models based solely on traditional financial indicators. This outcome confirms the growing importance of intangible resources in the banking sector and simultaneously distinguishes the present research from the existing literature, which predominantly relies on DEA analyses that use financial data and conventional production-based approaches. In Polish research, such as Mastalerz (2017) and Czerwonka (2019), efficiency assessments rely exclusively on financial variables—assets, deposits, operating costs and loan volumes—without accounting for intellectual capital as a productive input. Similarly, international studies employ classical financial sets of DEA variables: Turkish analyses apply CAMELS indicators (Wang et al., 2024), Serbian studies utilise the intermediation, operating and profitability approaches (Horvat et al., 2022), while a pan-European analysis of 471 banks relies on ROA, capitalisation, liquidity and provisioning measures (Licerán-Gutiérrez et al., 2025).

Asian studies also predominantly focus on financial metrics. Malaysian banks are evaluated using the SE-SBM model, which takes into account inputs such as deposits, assets, and equity, as well as non-interest income and investment, with outputs including these factors (Kasim et al., 2019). Chinese studies adopt an extended by-production SBM framework that incorporates undesirable outputs such as non-performing loans (Shi et al., 2023). None of these approaches integrates components of intellectual capital. The only research explicitly addressing intellectual capital, conducted on Nigerian listed banks (Olohunlana et al., 2023), evaluates IC

efficiency exclusively, without comparing it to financial efficiency or applying a dual-perspective framework. The present research addresses this gap by adopting a two-track efficiency approach using DEA, which separately assesses financial efficiency and intellectual capital efficiency, enabling the identification of divergences between the two dimensions and demonstrating that banks performing well in traditional DEA models may not necessarily excel in managing intangible resources.

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