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EFFICIENCY IN THE CROATIAN PHARMACEUTICAL SECTOR: A DECOMPOSITION APPROACH USING WDEA AND MPI

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Abstract

The Croatian pharmaceutical industry is a strategically important sector of the national economy, operating in a highly regulated market subject to strong international competition. This paper examines the efficiency and productivity of seven Croatian pharmaceutical manufacturers (NACE Rev. 2, Division 21.20) from 2018 to 2024 using Window Data Envelopment Analysis (WDEA) and the Malmquist Productivity Index (MPI). The sample comprises firms accounting for 93% of total sector revenue. Employee costs, total assets, and material expenses were used as inputs, while operating revenues and EBIT were treated as outputs. The results indicate that inefficiency is mainly associated with managerial and organisational factors rather than inappropriate production scale. The strongest productivity growth occurred in 2019/2020 (MPI +73.4%), followed by a decline *in 2020/2021 and 2021/2022 due to lower technical efficiency, although technological change remained positive during most of the period observed. The findings highlight the importance of managerial improvement and continuous investment in innovation for maintaining competitiveness and long-term resilience.*

Keywords: pharmaceutical industry, efficiency, productivity, WDEA, Malmquist Productivity Index (MPI)

1. INTRODUCTION

The pharmaceutical industry is a pillar of modern economic and healthcare systems worldwide, serving both as a commercial enterprise and a critical provider of public health. As a research-intensive sector characterized by substantial capital investment and long development cycles, the pharmaceutical industry operates within a complex ecosystem shaped by innovation, regulation, and market dynamics (European Federation of Pharmaceutical Industries and Associations [EFPIA], 2025). Its economic significance extends beyond direct revenue, contributing to employment, technological advancement, and national healthcare security. In Europe, the sector is among the most productive, with leading pharmaceutical companies investing around 20-25% of their revenues in research and development (PharmaCircle, 2025), while the sector also generates a substantial positive trade balance, reaching a record €313.4 billion in 2024 (Eurostat, 2025).

The strategic importance of the pharmaceutical industry has been particularly highlighted during recent global health crises, which underscored the need for resilient healthcare supply chains and strong innovation capacity. The COVID-19 pandemic demonstrated that pharmaceutical production capabilities directly impact national security and economic stability, with countries possessing robust domestic industries better able to respond to health emergencies (Tušek, Ježovita & Halar, 2021). This has led many nations to reconsider their industrial policies, recognizing that dependence on imported medicines and active pharmaceutical ingredients poses significant vulnerabilities during crises.

In Croatia, the pharmaceutical industry represents a strategic sector, combining traditional strengths with emerging challenges. Despite a relatively small economy, the sector maintains a notable international presence, with exports consistently growing even during economic downturns. It directly employs over 6,100 people, with additional employment in related industries, and maintains one of the highest R&D-to-revenue ratios among Croatian industrial sectors (Ministry of Economy, 2025). Nonetheless, structural challenges threaten its long-term competitiveness and strategic position.

This research examines the position of the Croatian pharmaceutical industry, which, despite notable innovative capabilities and international recognition, continues to face persistent efficiency challenges and increasing reliance on imports. Recent data indicate that pharmaceutical imports consistently exceed exports, with the largest imbalance recorded in 2024 (Croatian Bureau of Statistics, 2025). This trade imbalance is both an economic concern and a question of the sector's capacity to remain competitive within the European single market and globally. In this environment, efficiency optimization is not only a competitive advantage but also essential for long-term survival.

Globally, the pharmaceutical industry is undergoing significant transformation, driven by trends in personalized medicine and gene therapy, digitalization and artificial intelligence (AI), biosimilar and biotechnological development, and automation in manufacturing (Levy, 2023). While these developments offer opportunities for niche specialization, they require substantial investment and organizational adaptation, posing challenges for smaller markets such as Croatia. The sector's ability to navigate these technological transitions will largely determine its future competitiveness. Regulatory complexity further complicates operations. As an EU member state, Croatia must comply with stringent EU regulations while competing with both domestic and international firms.

This study focuses on manufacturers classified under NACE Rev. 2, Division 21.20 (Manufacture of pharmaceutical preparations). The initial sample frame was based on the sectoral analysis by Božić (2024), which identifies the ten largest pharmaceutical manufacturers in Croatia ranked by operating revenue for 2023. Of these ten, seven companies with complete financial data for the 2018–2024 period from the Orbis Europe BvD database were included in the final sample: Pliva Hrvatska d.o.o., JGL d.d., Belupo d.d., Hospira Zagreb d.o.o., PharmaS d.o.o., Krka-Farma d.o.o., and Fidifarm d.o.o. Together, these seven companies account for 93% of total sector revenue (Božić, 2024), ensuring that the findings are highly representative of the core of the domestic industry.

Previous research on pharmaceutical efficiency has largely focused on Western European and large emerging markets (Díaz & Sanchez-Robles, 2020; Gaebert & Staňková, 2020; Sun et al., 2025; Mahajan, Nauriyal, & Singh, 2020), while the operational efficiency of pharmaceutical sectors in Southeast European market, and Croatia in particular, remains largely unexplored. This study aims to address these gaps by analyzing efficiency and productivity in the Croatian pharmaceutical industry from 2018 to 2024, a period covering pre-pandemic conditions, the COVID-19 crisis, and post-pandemic recovery. To the best of our knowledge, this study is the first to apply Window Data Envelopment Analysis (WDEA), covering the period 2018–2024, with a full decomposition of efficiency into pure technical efficiency (PTE) and scale efficiency (SE) to the Croatian pharmaceutical sector. This decomposition is important because it quantitatively distinguishes whether inefficiency stems from managerial shortcomings (low PTE) or from operating at a suboptimal scale (low SE). Furthermore, this study provides the first longitudinal assessment of productivity changes in the Croatian pharmaceutical sector using the Malmquist Productivity Index (MPI).

By examining performance across this dynamic period and, crucially, by decomposing technical efficiency into its pure technical and scale components, the study seeks to identify the nature of inefficiency, whether it is primarily managerial or scale-related. This distinction is essential because the remedies for each type differ fundamentally. Establishing the primary source of inefficiency is therefore a prerequisite for formulating evidence-based recommendations to enhance sector competitiveness.

The significance of this research extends beyond academia, addressing both policy and strategic concerns. Understanding efficiency dynamics is essential for designing effective industrial policies, optimizing healthcare expenditure, and ensuring long-term medicine security. For managers, efficiency analysis offers benchmarking insights and identifies areas for operational improvement. For policymakers, it provides evidence for targeted support measures to address sector-specific challenges while maximizing the impact of public resources.

Following the introduction, Section 2 provides a comprehensive literature review on pharmaceutical efficiency and productivity, including both DEA studies and research on managerial determinants of performance. Section 3 outlines the methodological framework. Section 4 presents the empirical analysis, including data, variables, and results. Section 5 discusses the findings, with particular attention to distinguishing between managerial and scale sources of inefficiency. Section 6 concludes with policy implications and directions for future research.

2. LITERATURE REVIEW

Most literature on pharmaceutical efficiency either uses DEA to measure operational performance or investigates managerial and governance determinants. The question motivating this study is whether (in)efficiency in the Croatian pharmaceutical industry reflects managerial shortcomings or suboptimal scale.

A number of studies have applied DEA to evaluate the operational efficiency of pharmaceutical companies across different countries using inputs related to labor, capital, and materials, and outputs related to revenue and profit. Díaz and Sánchez-Robles (2020) analyzed 145 European pharmaceutical companies from 2010 to 2018 using an output-oriented DEA model with employees and total assets as inputs and turnover as output. Their findings revealed a decline in efficiency over time, with larger companies exhibiting higher efficiency levels. Notably, companies primarily engaged in pharmaceutical manufacturing were more efficient than those focused on R&D. Gaebert and Staňková (2020) conducted a large-scale study of 6,866 German pharmaceutical companies from 2009 to 2016, using capital, number of employees, and total assets as inputs, and operating revenue and value added as outputs. Their findings suggested a trend of improving efficiency, indicating that the decline in the number of pharmacies was mainly driven by market concentration rather than by adverse consequences of government policies. Sun, Rosli and Daud (2025) applied a three-stage DEA with undesirable outputs to 244 Chinese pharmaceutical companies, using total assets, operating costs, number of employees, and R&D investment as inputs, and operating revenue, operating profit, net cash flow, manufacturing permits, and pollution equivalent as outputs. Results indicated relatively low overall efficiency with significant regional variation. Mahajan, Nauriyal & Singh (2020) examined 141 Indian pharmaceutical firms using raw material costs, capital, advertising and marketing expenses, and wages as inputs, with net sales as output. The study concluded that firms were on average 19% inefficient, reflecting potential for operational improvements. Olasiuk, Sharma, Arora, Satapathy and Kumar (2025) examined nine Ukrainian pharmaceutical companies from 2018 to 2023 employing sales, general and administrative costs, and raw materials as inputs and revenue as output. Their study concluded that efficiency could be improved by minimizing marketing expenses and expanding business operations. Gascón, Lozano, Ponte and de la Fuente (2017) analyzed 37 large pharmaceutical laboratories between 2008 and 2013, incorporating average number of employees, total assets, and R&D expenditure as inputs, and net profit, market capitalization, and total sales as outputs. The study concluded that efficient laboratories conduct, on average, a greater number of financial transactions.

A growing stream of literature examines internal managerial practices, governance structures, and resource allocation strategies as potential determinants of firm performance. These studies are particularly relevant for interpreting the pure technical efficiency component of the decomposition. Sun et al. (2025) provides direct empirical evidence for the primacy of managerial factors. Their three-stage DEA with Tobit regression demonstrated that higher managerial costs and suboptimal personnel allocation significantly reduced operational efficiency even when controlling for firm size, ownership structure, and regional factors. Critically, they found that the composition of internal costs, particularly the ratio of administrative overhead to production costs, was a stronger predictor of efficiency than absolute size or market share. Asad, Popesko and Godman (2024) employed DEMATEL methodology based on expert surveys of European pharmaceutical companies to map causal relationships among internal performance drivers. Their analysis identified human resource competencies as the most important primary driver, with factors such as financial profitability and operational capabilities emerging as consequences rather than causes of strong foundational management. Sharda (2023) investigated ownership structure and managerial control in 41 Indian pharmaceutical firms using fixed-effects panel regression. The study uncovered a strong negative effect of concentrated managerial power – specifically, when a majority shareholder simultaneously holds CEO and board chairman roles – on strategic investment decisions and operational discipline. Tyagi, Hermosilla and Shah (2025) explored how regulatory transparency shapes managerial behavior. Analyzing nearly 10,000 clinical trials, they found that increased transparency makes managers more risk-averse, leading them to favor safe, exploitative projects over potentially efficiency-enhancing but uncertain initiatives. Adola et al. (2026) examined quality risk management systems in pharmaceutical manufacturers, identifying concrete deficiencies despite firms having basic frameworks in place. Deficits in formal risk identification, quantitative assessment, consistent procedure application, and staff training were widespread.

The key insight from this literature is that managerial factors, ranging from cost structures and human resource competencies to governance arrangements and risk management practices, significantly influence pharmaceutical firm performance. This study complements this literature by using DEA decomposition to identify whether inefficiency is managerial (low PTE) before any deeper investigation of which specific managerial practices are responsible.

Efficiency research on pharmaceutical firms is heavily concentrated in large economies (Germany, China, India, Spain). Studies of small, open economies within highly regulated frameworks are notably sparse. Díaz and Sánchez-Robles (2020) included multiple European countries but treated them as a homogeneous panel, obscuring country-specific institutional and regulatory effects. Gaebert and Staňková (2020) focused exclusively on Germany, a large, mature market with fundamentally different competitive dynamics than smaller EU economies. To the best of our knowledge, no study to date has applied Window DEA with efficiency decomposition (PTE/SE) to the Croatian pharmaceutical sector, nor has any study provided a longitudinal productivity assessment of this sector using the Malmquist Productivity Index (MPI). Methodologically, the combination of WDEA with MPI allows for both the decomposition of efficiency into managerial and scale components and the assessment of productivity changes over time, distinguishing technical efficiency change from technological change.

3. METHODOLOGY

Data Envelopment Analysis (DEA) is a widely used non-parametric technique for evaluating the relative efficiency of decision-making units (DMUs) that transform multiple inputs into multiple outputs. Unlike traditional parametric methods, DEA does not require an explicit functional form relating inputs to outputs, making it particularly suitable for complex production processes where multiple factors interact in unknown ways. The method identifies an efficiency frontier formed by the most efficient DMUs, against which all other units are benchmarked. Efficiency scores range from 0 to 1, with a score of 1 indicating that a DMU operates on the frontier and is fully efficient relative to its peers.

The standard DEA framework is most commonly expressed through the CCR model, developed by Charnes, Cooper, and Rhodes (1978), which assumes constant returns to scale (CRS). Since the present study adopts an output-oriented approach, the corresponding output-oriented CCR formulation is presented below. For a DMU_o, efficiency can be expressed as (Cooper, Seiford, and Tone, 2007):

$$max \qquad \theta = \mu_1 y_{10} + \ldots + \mu_S y_{S0}$$

subject to $\upsilon_1 x_{10} + \ldots + \upsilon_R x_{R0} = 1$

$$\mu_1 y_{1j} + \ldots + \mu_S y_{Sj} \leq \upsilon_1 x_{1j} + \ldots + \upsilon_R x_{Rj} \quad (\mathrm{j} = 1, \ldots, \mathrm{n})$$

$$\upsilon_i \geq 0, i = 1, \ldots R$$

$$\mu_r \geq 0, r = 1, \ldots S$$

Here, y_{sj}, $x_{rj} > 0$ denote the output and input values for DMU_j, where $j=1,\ldots,n$ represents the number of DMUs, R is the number of inputs, and S is the number of outputs. θ stands for the relative efficiency score obtained from the DEA model. The vectors ($x_{1j},\ldots,x_{Rj}$) and ($y_{1n}\ldots y_{Sn}$) represent the inputs and outputs of DMU_j, respectively, while ($v_1,\ldots,v_R$) and ($\mu_1,\ldots,\mu_S$) denote the corresponding input and output weights. The efficiency score takes values between 0 and 1, where a value of 1 indicates that a DMU is located on the efficiency frontier, while values below 1 indicate relative inefficiency. The resulting measure, Technical Efficiency (TE), indicates whether the observed DMU could proportionally increase its output usage while maintaining the same level of inputs.

The BCC model, introduced by Banker, Charnes, and Cooper (1984), extends this framework by relaxing the assumption of constant returns to scale and instead assuming variable returns to scale (VRS). The formulation is identical to the CCR model, with the addition of a convexity constraint:

$$\sum_{j=1}^{n} \lambda_j = 1$$

This adjustment allows the model to distinguish inefficiencies resulting from managerial performance, known as Pure Technical Efficiency (PTE), from those related to the scale of operations. Scale Efficiency (SE) is calculated as the ratio of Technical Efficiency (TE) from the CCR model to PTE from the BCC model, providing insight into whether a DMU operates at an optimal scale.

For longitudinal analyses, DEA can be extended using the Window Data Envelopment Analysis (WDEA) framework, first proposed by Charnes et al. (1984). In WDEA, each DMU observed at different time periods is treated as a separate entity, while temporal continuity is maintained through overlapping windows. If the window length is denoted by w, the dataset is divided into overlapping subsets, allowing the performance of each DMU to be tracked over time, and enabling the assessment of both efficiency dynamics and stability. This approach is particularly effective in industries characterized by rapid technological change or fluctuating market conditions, as it captures both short-term and long-term efficiency variations. Importantly, it also makes the method suitable for applications with a relatively small number of DMUs, since the time dimension increases the number of observations available for analysis without the need to expand the cross-sectional sample.

To complement efficiency assessment, productivity changes over time are measured using the Malmquist Productivity Index (MPI), originally introduced by Caves et al. (1982) and further formalized within the DEA framework by Färe et al. (1994). The MPI captures changes in total factor productivity over time and allows their decomposition into technical efficiency change (TEC) and technological change (TC). For a DMU moving from period *t* to *t+1*, the MPI is defined as:

$$MPI = \left[\frac{D^t(x^{t+1}, y^{t+1}}{D^t(x^t, y^t)} \cdot \frac{D^{t+1}(x^{t+1}, y^{t+1}}{D^{t+1}(x^t, y^t)}\right]^{\frac{1}{2}}$$

Where D^t (x, y) represents the input-oriented distance function that measures how far a given observation *(x, y)* is from the efficiency frontier in period *t*. In practical terms, this function evaluates the relative position of a DMU in a given period with respect to the production technology. Specifically, values equal to 1 indicate no change in productivity between periods, values greater than 1 indicate an increase in productivity, while values less than 1 indicate a decline in productivity. The use of distance functions from both periods (t and t+1), as well as cross-period evaluations, enables the comparison of performance under different technological conditions. The index can be decomposed into two multiplicative components:

$$MPI = \underbrace{\frac{D_0^{t+1}(x^{t+1}, y^{t+1})}{D_0^t(x^t, y^t)}}_{\text{TEC}} * \underbrace{\left[\left(\frac{D_0^t(x^{t+1}, y^{t+1})}{D_0^{t+1}(x^{t+1}, y^t)}\right)\left(\frac{D_0^t(x^t, y^t)}{D_0^{t+1}(x^t, y^t)}\right)\right]^{\frac{1}{2}}}_{\text{TC}}$$

Here, TEC measures ımprovements or declines in a tırm´s efficiency relative to the frontier and reflects the “catch-up” effect, while TC indicates shifts in the efficiency frontier itself due to innovation or technological progress and reflects the “frontier shift” effect.

4. EMPIRICAL ANALYSIS

The analysis covers the period from 2018 to 2024 and employs Window Data Envelopment Analysis (WDEA), which extends classical DEA by incorporating a temporal dimension. This allows efficiency assessment across multiple periods and captures performance changes over time. A three-year window length was chosen, resulting in five overlapping windows: 2018–2020, 2019–2021, 2020–2022, 2021–2023, and 2022–2024. The number of windows was calculated following Cooper, Seiford, and Tone (2007) using the formula w = k − p + 1 = 7 − 3 + 1 = 5, where k is the total number of years and p the window length. The total number of “distinct” decision-making units (DMUs), allowing multiple observations and a larger set of inputs and outputs without losing discriminatory power, was computed as Distinct DMUs = n× p× w = 7 × 3× 5 = 105, with n representing the number of companies. Considering partial overlap across windows, the effective number of DMU observations is k × n = 7

× 7 = 49, which satisfies the DEA requirement that the number of DMUs be at least three to four times the total number of inputs and outputs, ensuring reliable efficiency estimation (Charnes, Cooper, & Rhodes, 1978).

4.1. Data and Variables

Official data from the Croatian business register CompanyWall (2024) show that this sector consists of 58 active companies, generating total annual revenues of €1.48 billion in 2024. The market is characterized by a high degree of concentration, confirming its oligopolistic structure.

Data were obtained from the Orbis Europe BvD database for companies classified under NACE Rev. 2, Division 21.20 (Manufacture of pharmaceutical preparations). The initial sample frame was based on the sectoral analysis by Božić (2024), which identifies the ten largest pharmaceutical manufacturers in Croatia ranked by operating revenue for 2023. Of these ten, seven companies with complete financial data for the 2018–2024 period were included in the final sample: Pliva Hrvatska d.o.o., JGL d.d., Belupo d.d., Hospira Zagreb d.o.o., PharmaS d.o.o., Krka-Farma d.o.o., and Fidifarm d.o.o. Three companies from the Božić (2024) top-ten list are not included in the final sample (Genera d.d., Yasenka d.o.o., and Fagron Hrvatska d.o.o.) all of which were excluded due to incomplete financial data for the 2018–2024 period. Božić (2024) reports that the top 10 companies represent 92% of sector revenue. However, according to CompanyWall (2024), the seven sampled firms alone account for over 93% of total sector revenue, confirming that the exclusion of the three firms with incomplete data (Genera d.d., Yasenka d.o.o., and Fagron Hrvatska d.o.o.) does not materially affect the sector-level conclusions.

Three inputs were selected for the analysis: employee costs (Mahajan Nauriyal & Singh, 2020), total assets (Gascón et al., 2017; Gaebert & Staňková, 2020; Díaz & Sánchez-Robles, 2020; Sun et al., 2025), and material costs (Sun et al., 2025; Mahajan, Nauriyal & Singh, 2014). Škuflić and Novinc (2024) found that unit labor costs are a significant predictor of pharmaceutical sector revenue in Croatia, supporting the inclusion of employee costs as an input in our DEA model. Total assets were selected as they comprehensively capture the capital resources available to management, including both tangible and intangible assets relevant to pharmaceutical operations. Although R&D expenditure is recognized as an important input in the pharmaceutical industry due to its role in innovation and value creation, it was not included in the analysis because the data are not available in the dataset for the firms and years included in the study period. Two outputs were used: operating revenue (Gaebert & Staňková, 2020; Díaz & Sánchez-Robles, 2020; Sun et al., 2025) and EBIT (Lin et al. 2021). Due to the small number of DMUs and the relatively large number of input and output variables, the reliability and discriminatory power of DEA and MPI may be limited, and the results should therefore be interpreted with caution.

An output-oriented specification was adopted given the export-oriented nature of the Croatian pharmaceutical industry. Sector-level data confirm the strategic importance of international markets, with pharmaceutical exports reaching €1.1 billion in 2023 and growing at an accelerating pace (Božić, 2024). This orientation is therefore appropriate for identifying opportunities for output expansion and revenue growth in a globally competitive environment.

Descriptive statistics for the input and output variables indicate a continuous increase in employee costs, operating revenue, and EBIT over the period, with a moderate rise in total assets and material costs.

Table 1 Descriptive statistics of inputs and outputs for the period from 2018 to 2024, in thousands of euros

2018	**Costs of employees**	**Total assets**	**Material costs**	**Operating revenue**	**EBIT**
Max	67620.2	851726.8	284874.8	532812.4	43542.71
Min	1468.65	40390.73	6565.81	9742.95	640.45
Average	19019.58	214631.3	57472.97	118338.6	11236.92
SD	21594.15	266149.6	93443.93	172568.5	13966.57
2019					
Max	72003	751101.3	289196.7	626222.5	153808
Min	1481	5944.63	6945.19	9944.59	829.1
Average	20715.71	191811.3	59773.82	135761	26703.27
SD	22929.53	236644.3	94309.21	203756.8	52085.13
2020					
Max	79260.77	790969.1	309320.6	583035.1	97488.6
Min	1631.82	6352.26	8042.3	12280.31	957.66
Average	22169.37	203940.7	63778.18	138963.7	25551.67
SD	25159.44	248616.2	100878.5	186375.9	33947.65
2021					
Max	83925.86	727411.9	335116.9	613724.5	108239.6
Min	1222.66	6651.63	9124.01	13252.11	625.63
Average	23508.55	204146.7	69225.27	144748.4	25943.76
SD	26618.28	226229.6	109137.9	196447.8	35986.11
2022					
Max	91355.84	715062.6	324967.4	641491.7	117636.8
Min	1124.21	9654.03	10429.64	14342.05	326
Average	25709.09	212662.1	75925.12	157263.9	29364.55
SD	29038.02	222432.4	103432.2	204915.8	38641.62
2023					
Max	105286.5	1486147	363737.5	719247.9	132118.4
Min	1178.78	9631.94	11511.94	16227.09	1044.46
Average	28483.36	341770.9	86363.84	173959.8	30977.48
SD	33662.29	479871.2	115726.4	231095	42916.31
2024					
Max	114313.2	2146276	393035.9	790138.3	169209.8
Min	1322.67	10675.43	13055.98	18364.94	1503.2
Average	32062.56	453273.8	92166.84	190943.3	37255.75
SD	36644.97	702519	125729.8	255458.4	55260.42

Source: Authors

Correlation analysis confirmed the isotonicity condition required for DEA, showing that all inputs are positively correlated with the outputs, thus validating the suitability of the dataset for efficiency analysis. The correlation matrix for all observed years is presented in Table 2.

Table 2 Correlation matrix

2018	**Costs of employees**	**Total assets**	**Material costs**	**Operating revenue (Turnover)**	**Operating profit (loss) [EBIT]**
Costs of employees	1.000	0.972	0.953	0.975	0.951
Total assets	0.972	1.000	0.991	0.993	0.985
Material costs	0.953	0.991	1.000	0.992	0.959
Operating revenue (Turnover)	0.975	0.993	0.992	1.000	0.969
Operating profit (loss) [EBIT]	0.951	0.985	0.959	0.969	1.000
2019					
Costs of employees	1.000	0.985	0.943	0.968	0.944
Total assets	0.985	1.000	0.984	0.994	0.983
Material costs	0.943	0.984	1.000	0.989	0.997
Operating revenue (Turnover)	0.968	0.994	0.989	1.000	0.995
Operating profit (loss) [EBIT]	0.944	0.983	0.997	0.995	1.000
2020					
Costs of employees	1.000	0.990	0.956	0.980	0.862
Total assets	0.990	1.000	0.985	0.995	0.898
Material costs	0.956	0.985	1.000	0.986	0.880
Operating revenue (Turnover)	0.980	0.995	0.986	1.000	0.910
Operating profit (loss) [EBIT]	0.862	0.898	0.880	0.910	1.000
2021					
Costs of employees	1.000	0.992	0.953	0.982	0.931
Total assets	0.992	1.000	0.967	0.992	0.965
Material costs	0.953	0.967	1.000	0.985	0.948
Operating revenue (Turnover)	0.982	0.992	0.985	1.000	0.960
Operating profit (loss) [EBIT]	0.931	0.965	0.948	0.960	1.000
2022					
Costs of employees	1.000	0.989	0.974	0.987	0.952
Total assets	0.989	1.000	0.975	0.987	0.983
Material costs	0.974	0.975	1.000	0.996	0.967
Operating revenue (Turnover)	0.987	0.987	0.996	1.000	0.973
Operating profit (loss) [EBIT]	0.952	0.983	0.967	0.973	1.000
2023					
Costs of employees	1.000	0.972	0.983	0.992	0.990
Total assets	0.972	1.000	0.993	0.987	0.994
Material costs	0.983	0.993	1.000	0.997	0.994
Operating revenue (Turnover)	0.992	0.987	0.997	1.000	0.995
Operating profit (loss) [EBIT]	0.990	0.994	0.994	0.995	1.000
2024					
Costs of employees	1.000	0.963	0.979	0.990	0.978
Total assets	0.963	1.000	0.994	0.985	0.996
Material costs	0.979	0.994	1.000	0.997	0.995
Operating revenue (Turnover)	0.990	0.985	0.997	1.000	0.991
Operating profit (loss) [EBIT]	0.978	0.996	0.995	0.991	1.000

Source: Authors

4.2. Results

The analysis employs WDEA to assess relative efficiency across overlapping three-year periods from 2018 to 2024, as well as the MPI to evaluate productivity changes over time.

The WDEA results range from 0 to 1, where 1 indicates full relative efficiency, and values closer to 0 reflect relative inefficiency. The average results for TE, PTE, and SE for the analyzed companies indicate notable variation across the sector. TE measures overall efficiency, PTE captures pure managerial efficiency, and SE reflects scale efficiency. Due to the relatively small number of decision-making units, estimating a separate annual BCC model would not provide a stable efficiency frontier. Therefore, the study relies primarily on the Window DEA approach, which increases the number of observations and ensures more robust efficiency estimates over time. As a consequence, scale efficiency is interpreted cautiously as an indicator of deviation from optimal scale, without explicitly inferring returns-to-scale classification.

Table 3 Average TE, PTE and SE of sampled pharmaceutical companies in the Republic of Croatia from 2018 to 2024

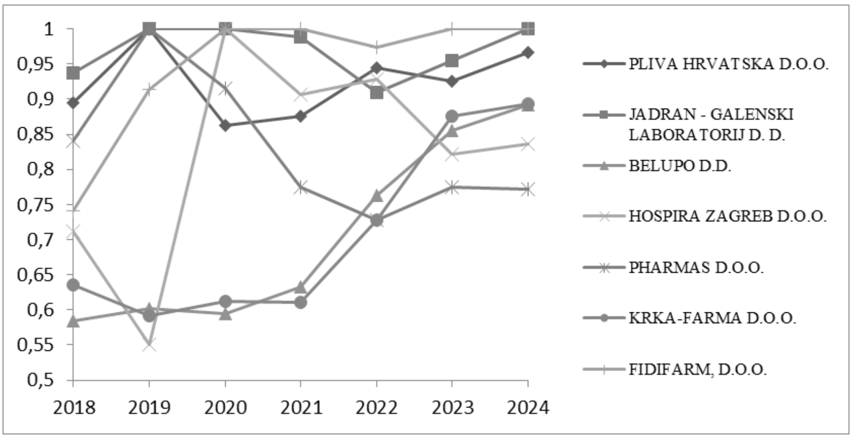
	TE	PTE	SE
PLIVA HRVATSKA d.o.o.	0.91736941	0.984274429	0.932026052
JGL d.d.	0.969263952	0.980218043	0.988824843
BELUPO d.d.	0.690692022	0.709997343	0.972809306
HOSPIRA ZAGREB d.o.o.	0.853461793	0.868110682	0.983125552
PHARMAS d.o.o.	0.827647005	0.882660127	0.937673494
KRKA-FARMA d.o.o.	0.687527824	0.827606326	0.830742591
FIDIFARM d.o.o.	0.966037168	1	0.966037168
Average	**0.844571311**	**0.893266707**	**0.944462715**

Source: Authors

JGL and Fidifarm emerge as the best-performing firms, with JGL achieving near-perfect scores across all dimensions (TE 0.969, PTE 0.980, SE 0.989) and Fidifarm operating on the efficiency frontier with perfect PTE (1.000). Pliva Hrvatska, despite high managerial efficiency (PTE 0.984), exhibits the lowest scale efficiency (SE 0.932), suggesting that its suboptimal scale is the primary constraint on overall performance. Krka-Farma and Belupo show the lowest overall TE (0.688 and 0.691 respectively), but for different reasons: Krka-Farma's inefficiency stems from both managerial (PTE 0.828) and scale (SE 0.831) issues, while Belupo's problem is predominantly managerial (PTE 0.710) given its high scale efficiency (SE 0.973). Hospira Zagreb and PharmaS display moderate efficiency with room for improvement in managerial performance.

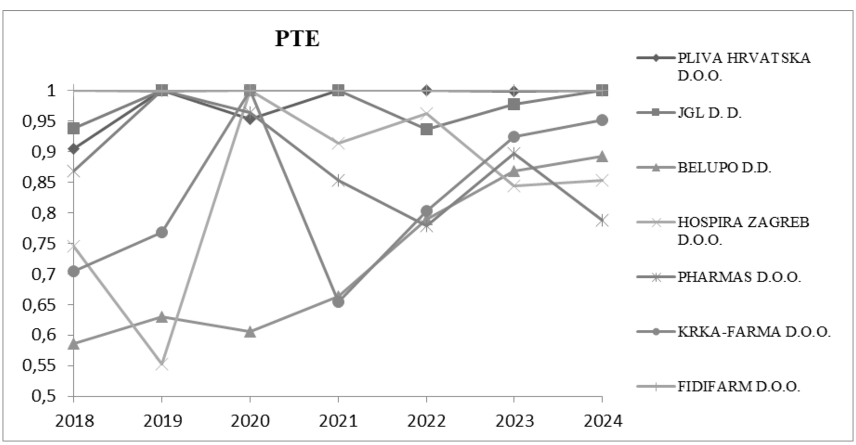
The following graphs present the results of TE along with PTE and SE as its fundamental components. The reported values in graphs are obtained as the arithmetic mean across all overlapping windows in which each year appears ("average by term"), providing a single representative efficiency score per year for clearer temporal interpretation. Since years in the middle of the observed period are included in multiple overlapping windows, their reported values are calculated as averages across several window evaluations, whereas the edge years (2018 and 2024) are based on a smaller number of overlapping windows due to their position at the beginning and end of the sample period.

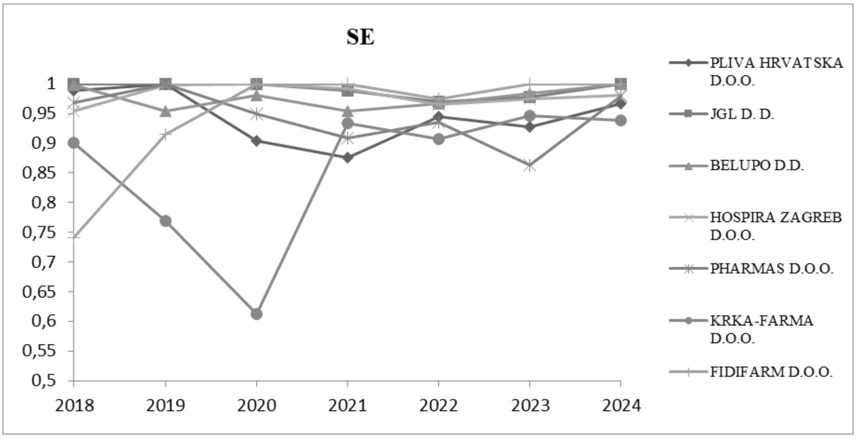
Graph 1 Technical Efficiency (TE) of Pharmaceutical Companies in the Republic of Croatia from 2018 to 2024



Source: Authors

Graph 2 Pure Technical Efficiency (PTE) and Scale Efficiency (SE) of Pharmaceutical Companies in the Republic of Croatia from 2018 to 2024



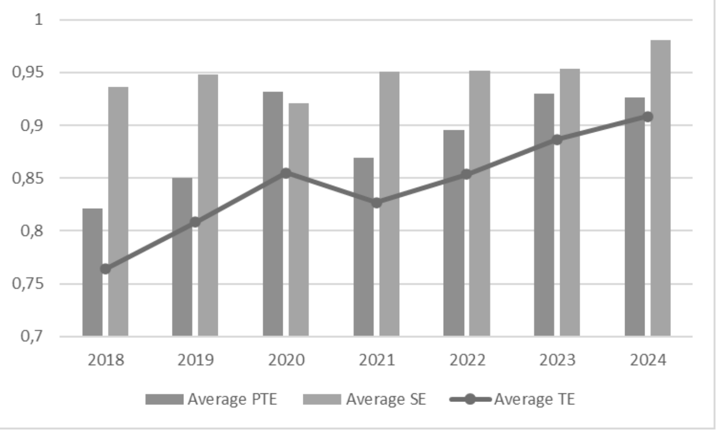


Source: Authors

The analysis of technical efficiency over time reveals distinct patterns among the seven firms. JGL and Fidifarm consistently achieved very high and stable results throughout the entire period. Pliva Hrvatska experienced fluctuations but maintained strong managerial efficiency, with scale efficiency showing gradual improvement. Belupo demonstrated steady growth in managerial efficiency, nearly doubling its PTE from 2018 to 2024. Hospira Zagreb exhibited notable efficiency gains during 2019–2020, while Krka-Farma showed gradual improvement in both dimensions over time. Pharmas maintained relatively stable performance with moderate efficiency scores. The COVID-19 pandemic significantly influenced the pharmaceutical industry, driving increased demand for medicines and prompting rapid adaptation in production processes, research and development, and operational structures (Tušek et al., 2021).

The following graph presents the aggregated results for all seven companies from 2018 to 2024.

Graph 3 Average values of TE, PTE and SE of selected pharmaceutical companies in Croatia from 2018 to 2024



Source: Authors

Between 2018 and 2024, the average values of TE, PTE, and SE indicate a gradual improvement in the operational efficiency of the pharmaceutical sector in Croatia. TE, which measures the overall ability to convert resources into outputs, started at 0.78 in 2018 and experienced fluctuations, reaching 0.88 by 2024. PTE, which focuses on operational efficiency independent of company size, showed a stable trend averaging 0.89 throughout the period, demonstrating that companies maintained consistent managerial performance. SE, reflecting whether companies operate at an optimal scale, averaged 0.94, indicating that firms are generally well-aligned with their most productive scale of operations.

The Malmquist Productivity Index (MPI) and its components, Technical Efficiency Change (TEC) and Technological Change (TC), provide further insights into productivity dynamics.

Table 4 Malmquist Productivity Index (MPI), Technical Efficiency Change (TEC), and Technological Change (TC) over the period from 2018 to 2024

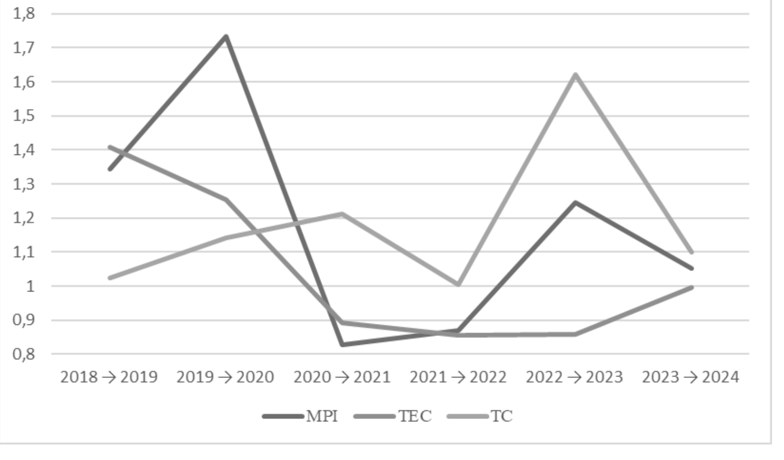
	MPI	TEC	TC
2018 → 2019	1.344191	1.40756	1.023549
2019 → 2020	1.734431	1.253402	1.142935
2020 → 2021	0.827222	0.892508	1.211873
2021 → 2022	0.868678	0.856222	1.004331
2022 → 2023	1.246433	0.859476	1.622339
2023 → 2024	1.051246	0.995875	1.09917
Geo. Average	1.1787	1.044174	1.184033
Max	1.476677	1.113631	1.303442
Min	1.004027	0.954846	0.983884
SD	0.16059	0.0584	0.129394

Source: Authors

During the period from 2018 to 2024, overall productivity measured by the Malmquist Productivity Index (MPI) exhibited a generally positive trend, with a geometric average of 1.179. The largest increase in productivity occurred between 2019 and 2020, when the MPI rose by 73.4%. This growth was driven by both Technical Efficiency Change (TEC) of 25.3% and Technological Change (TC) of 14.3%. The most significant decline in productivity was observed between 2020 and 2021, when MPI fell by 17.3%, primarily driven by a decrease in TEC of 10.7%. Productivity also declined between 2021 and 2022 by 13.1%, again due to negative TEC (−14.4%), while TC remained positive. The final two periods (2022–2023 and 2023–2024) saw productivity recover, with growth of 24.6% and 5.1% respectively.

The analysis reveals that fluctuations in TEC were the main driver of overall productivity changes throughout the observed period, with TEC showing considerable volatility (SD 0.058). TC, while generally positive and more stable (SD 0.129), made a smaller contribution to productivity dynamics. In particular, the decline in MPI between 2020 and 2021 is mainly driven by a decrease in TEC (0.893), while TC remains positive (1.212), indicating that the productivity decline is attributable to efficiency deterioration rather than technological regress.

Graph 4 MPI, TEC and TC over the period from 2018 to 2024



Source: Authors

The highest productivity growth occurred from 2019 to 2020, followed by a significant decline in the subsequent period.

5. DISCUSSION

The decomposition of technical efficiency into its PTE and SE components provides one of the most valuable insights of this study. While overall technical efficiency (TE) offers a summary measure of performance, it is the distinction between PTE and SE that reveals the nature of inefficiency. Specifically, whether firms underperform because of how they manage their resources (managerial inefficiency) or because they operate at a suboptimal size (scale inefficiency). This distinction is important because the remedies for each type of inefficiency differ fundamentally: managerial inefficiency calls for improvements in internal processes, resource allocation, and organizational capabilities, while scale inefficiency suggests a need for consolidation, expansion, or restructuring.

The analysis reveals that for four of the seven analyzed firms, Belupo, Hospira Zagreb, PharmaS, and to some extent Krka-Farma, low overall efficiency is primarily driven by low pure technical efficiency (PTE), while scale efficiency (SE) remains high. For Pliva Hrvatska, the opposite pattern holds: high PTE (0.984) but the lowest SE in the sample (0.932), suggesting that the firm operates at a suboptimal scale. JGL and Fidifarm achieve high scores on both dimensions, demonstrating that excellence in both managerial effectiveness and scale appropriateness is achievable within the Croatian context. The Malmquist Productivity Index analysis shows that productivity growth peaked in 2019–2020 (MPI +73.4%), driven by both technical efficiency change (TEC) and technological change (TC), followed by a decline in 2020–2022 driven by negative TEC while TC remained positive. Productivity recovered in 2022–2023 (MPI +24.6%) and continued modest growth in 2023–2024 (MPI +5.1%).

These findings both confirm and diverge from previous research. The predominance of managerial inefficiency over scale inefficiency is consistent with Sun, Rosli and Daud (2025) and Mahajan, Nauriyal & Singh (2020), who similarly found that pure technical efficiency was the binding constraint in Chinese and Indian pharmaceutical firms, respectively. Both studies reported that low PTE, reflecting shortcomings in cost structures, personnel allocation, and internal processes, was the primary driver of overall inefficiency, with scale efficiency remaining relatively high. Our results align with this pattern for the majority of Croatian firms. However, our findings diverge from Díaz and Sánchez-Robles (2020) and Gaebert and Staňková (2020), who reported that larger European firms achieved higher efficiency primarily through scale advantages. One explanation for this divergence is that the Croatian pharmaceutical market, characterized by a high degree of export orientation and, more generally, concentrated ownership structures (OECD, 2025), differs structurally from the large, mature markets (Germany, Spain) analyzed in those studies. Unlike in those contexts, scale efficiency in Croatia is already high for most firms (average SE of 0.94 over the period), leaving managerial factors as the remaining differentiator. The one exception is Pliva Hrvatska, where scale inefficiency persists, possibly reflecting historical legacies of past investments or excess capacity, which is more consistent with the pattern documented by Díaz and Sánchez-Robles (2020) for large European manufacturers.

The productivity dynamics revealed by the MPI can also be compared with prior research. The sharp increase in MPI during 2019–2020 (73.4%) coincides with the onset of the COVID-19 pandemic, a period when global demand for pharmaceutical products surged and Croatian manufacturers rapidly adapted production processes (Tušek, Ježovita & Halar, 2021). The subsequent decline in 2020–2022, driven by negative technical efficiency change while technological change remained positive, suggests that firms struggled to sustain the operational improvements achieved during the initial crisis response, even as they continued to adopt new technologies. This pattern, where technical efficiency change is more volatile than technological change, has been observed in other crisis contexts, including the analysis of Ukrainian pharmaceutical firms by Olasiuk et al. (2025), who reported similar fluctuations in TEC following external shocks.

As our model includes only financial inputs (employee costs, total assets, material costs) and outputs (operating revenue, EBIT), it does not directly measure managerial practices, governance structures, cost compositions, or risk management systems. The following discussion therefore offers potential explanations drawn from the existing literature, not direct findings of this study.

The existing literature on managerial determinants of pharmaceutical firm performance offers several potential explanations for why low pure technical efficiency might occur. Sun et al. (2025), in their three-stage DEA with Tobit regression, provide empirical evidence that higher managerial costs and suboptimal personnel allocation significantly reduce operational efficiency. They found that the composition of internal costs, particularly the ratio of administrative overhead to production costs, was a stronger predictor of efficiency than absolute size or market share. For Croatian firms with low PTE, such as Belupo and Hospira Zagreb, this suggests that a critical examination of cost structures and headcount allocation may reveal opportunities for improvement, although our data do not allow us to confirm this directly.

Asad, Popesko and Godman (2024) employed DEMATEL methodology based on expert surveys of European pharmaceutical companies to map causal relationships among internal performance drivers. Their analysis identified human resource competencies as the most important primary driver, with factors such as financial profitability and operational capabilities emerging as consequences rather than causes of strong foundational management. This finding implies that when firms exhibit low PTE, the root cause may lie in insufficiently developed managerial and staff capabilities, a challenge that cannot be solved by financial engineering or scale adjustments alone. Whether this applies to the Croatian context remains an open question for future research.

Sharda (2023) investigated the impact of ownership structure and managerial control on strategic decisions in Indian pharmaceutical firms, uncovering a strong negative effect of concentrated managerial power on strategic investments and operational discipline. When a majority shareholder simultaneously holds the dual roles of CEO and board chairman, oversight mechanisms weaken. This "principal-principal" agency problem may be particularly relevant for Croatian companies with concentrated ownership structures, where governance mechanisms may be less formalized and independent oversight limited.

Tyagi, Hermosilla and Shah (2025) explored how regulatory frameworks shape managerial behavior, finding that increased transparency makes managers more risk-averse, leading them to favor safe, exploitative projects over radical or efficiency-enhancing innovation. In a small, regulated market like Croatia, where reputational risks may be perceived as particularly salient, such behavioral dynamics could contribute to low PTE. Adola et al. (2026) examined quality risk management systems in pharmaceutical manufacturers, identifying concrete deficiencies in formal risk identification, quantitative assessment, consistent procedure application, and staff training. These findings highlight that inefficiency can stem not from a lack of strategic intent, but from the failure to systematically implement foundational management processes.

The present analysis cannot determine which of these factors are most relevant for each individual Croatian firm. What it establishes is that for the majority of firms in our sample, inefficiency is fundamentally managerial in nature, the problem lies in how resources are managed at the current scale, not in the scale itself. For Pliva Hrvatska, by contrast, the diagnostic implication is different: here the challenge is scale-related, suggesting that attention should focus on capacity utilization, asset restructuring, or strategic decisions about the optimal size of operations. JGL and Fidifarm, with their strong performance on both dimensions, demonstrate that it is possible to achieve excellence in both managerial effectiveness and scale appropriateness within the Croatian context, providing potential benchmarks for other firms in the sector.

The main limitation of this study is that it relies exclusively on financial indicators; it cannot directly observe the managerial practices, governance structures, or organizational processes that may explain the measured inefficiencies. Another limitation is the absence of R&D expenditure in the dataset, which restricts the ability to fully capture innovation-related inputs that are particularly relevant in the pharmaceutical industry. Future studies should incorporate R&D data where available and combine quantitative efficiency analysis with qualitative methods (surveys, interviews, case studies) to directly link PTE scores with specific managerial practices. Extending the time horizon would allow assessment of long-term post-pandemic effects. Additionally, when longer time series become available, including R&D variables would enable comparison with innovation-focused studies.

5. CONCLUSION

This study analyzes the efficiency and productivity dynamics of the Croatian pharmaceutical manufacturing sector from 2018 to 2024 based on seven manufacturers, which together account for 93% of total sector revenue. It represents the first application of WDEA with efficiency decomposition to the Croatian pharmaceutical sector, and the first longitudinal productivity assessment using MPI for this context.

The main findings can be summarized as follows. First, the decomposition of technical efficiency into PTE and SE components reveals that when inefficiency occurs, it is predominantly managerial in character. For four of the seven analyzed firms, low efficiency stems from pure technical inefficiency rather than scale. Scale inefficiency is the issue for only one firm (Pliva Hrvatska), while two firms (JGL and Fidifarm) achieve high scores on both dimensions. This finding is significant because the appropriate remedy depends on whether inefficiency is managerial or scale-related. Managerial inefficiency calls for internal organizational improvements: optimizing resource allocation, strengthening human resource competencies, improving governance structures, and enhancing operational discipline. Scale inefficiency, by contrast, suggests a need for strategic decisions about capacity utilization, consolidation, or restructuring.

The productivity analysis via the Malmquist Index adds a further dimension, showing that while the sector experienced strong productivity growth during the initial phase of the COVID-19 pandemic (2019–2020), this was followed by a decline driven by negative technical efficiency change (2020–2021). This pattern underscores the vulnerability of productivity gains when efficiency improvements are not sustained over time.

Having established that managerial factors are the dominant source of inefficiency for most firms in our sample, this study draws on the broader empirical literature to identify the types of managerial problems most commonly associated with low pure technical efficiency in pharmaceutical firms. While the present analysis cannot determine which of these factors are most relevant for each individual firm, it establishes that for the majority of firms, the problem lies in how resources are managed at the current scale.

For managers, the findings suggest that firms with low pure technical efficiency (Belupo, Hospira Zagreb, PharmaS, Krka-Farma) should prioritize internal organizational improvements – optimizing cost structures, strengthening human resource competencies, and improving governance discipline – rather than seeking scale expansion. Pliva Hrvatska, by contrast, should address capacity utilization and asset restructuring. JGL and Fidifarm serve as benchmarks for excellence in both dimensions. For policymakers, sectoral support should focus on managerial capacity building (training programs, governance reforms, knowledge transfer) rather than merger facilitation, since scale efficiency is already high for most firms. Sustained investment in innovation and technology is critical, as productivity gains proved vulnerable when technological progress stalled during 2020–2021.

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EFIKASNOST HRVATSKOG FARMACEUTSKOG SEKTORA: DEKOMPOZICIJSKI PRISTUP KORIŠTENJEM WDEA I MPI METODE

Sažetak

Hrvatska farmaceutska industrija strateški je važan dio nacionalnog gospodarstva, ali se suočava s izazovima reguliranog tržišta i međunarodne konkurencije. U radu se analiziraju učinkovitost i produktivnost sedam velikih hrvatskih proizvođača lijekova (NKD Rev. 2, Odjeljak 21.20) u razdoblju od 2018. do 2024. primjenom metoda Window Data Envelopment Analysis (WDEA) i Malmquistova indeksa produktivnosti (MPI). Uzorak obuhvaća poduzeća koja ostvaruju 92 % ukupnih prihoda sektora. Kao inputi korišteni su troškovi zaposlenika, ukupna imovina i materijalni troškovi, dok su outputi poslovni prihodi i EBIT. Rezultati pokazuju da neučinkovitost većine poduzeća proizlazi ponajprije iz menadžerskih i organizacijskih nedostataka. Nalazi upućuju na potrebu jačanja upravljačkih kapaciteta i kontinuiranog ulaganja u inovacije radi očuvanja konkurentnosti i dugoročne otpornosti domaće proizvodnje lijekova.

Ključne riječi: farmaceutska industrija, učinkovitost, produktivnost, WDEA, Malmquist Productivity Index (MPI).

JEL klasifikacija: C14, C61, D24, L65, O14.