

PRE-2020 TRENDS OF AI ADOPTION AND COMPARATIVE ADVANTAGE IN EUROPEAN COUNTRIES


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Abstract. *Rapid advances in technology, especially AI applications, have contributed to economic transformation at both the microeconomic and macroeconomic levels. Given its substantial potential, AI adoption can become an important source of a country's comparative advantage. This study examines whether European countries achieved a comparative advantage derived from AI applications during the period 2014–2019. Comparative advantage is assessed using the RSCA index, where positive values indicate its presence. The index is calculated based on the AI patent applications per one million people. The findings reveal that only a limited number of European countries possess a comparative advantage in AI, and that these countries are at varying levels of economic development. This suggests that a nation's level of economic development is not a decisive factor for the emergence of innovative ideas driven by AI adoption.*

Key words: *artificial intelligence, comparative advantage, RSCA, Europe*

JEL Classification: F15, F41, O34, O52

1. INTRODUCTION

In recent years, the application of artificial intelligence (AI) has expanded to a scale that was previously unimaginable. Its considerable potential is evident in its integration across diverse domains, including healthcare, medicine, machine learning, and engineering. Although still in its formative stages, AI is increasingly permeating nearly all aspects of human life. While its adoption offers substantial benefits, public discourse often emphasises the significant risks associated with its use. Given this dual nature, where AI represents both a driver of innovation and a source of concern, understanding its broader

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economic implications becomes essential. Against this, the paper explores the role of AI adoption in shaping and enhancing comparative advantages.

This paper aims to examine the comparative advantage arising from the innovative application of artificial intelligence (AI) in European countries. The level of innovation in AI is assessed through the number of AI-related patent applications, which serve as a widely recognised indicator of technological advancement and inventive activity. Patents not only reflect a country's capacity to generate new technologies, but also provide a means of protecting and commercialising innovations, which in turn influences its position in global markets. By linking patent activity to measures of comparative advantage, this study offers insights into the role of AI-driven innovation in enhancing economic competitiveness. This research employs the Revealed Symmetric Comparative Advantage (RSCA) index to empirically assess the hypothesis that the adoption of artificial intelligence improves the competitiveness of European countries in technology-intensive sectors.

Besides the introduction and concluding remarks, the paper is structured into three interconnected sections. The first section addresses the definition of artificial intelligence (AI), the significance of its application, and its transformative impact on economic functioning. The second section focuses on the attainment of comparative advantage through AI application and the methods used to measure it. The third section presents the results of the analysis concerning the extent to which European countries have achieved a comparative advantage in this domain.

2. THE PURPOSE AND SIGNIFICANCE OF ARTIFICIAL INTELLIGENCE

One of the main forces behind innovation, economic expansion, and social transformation is thought to be the digitisation of the economy (Afonasova et al., 2018). It is part of the Fourth Industrial Revolution, also known as Industry 4.0 or Digital Transformation (Rosa et al., 2022, p. 3). In its strictest definition, the digital economy refers to the segment of the economy comprising businesses that rely heavily on digital technologies and whose operations center on digital products and services. This industry incorporates the actual digital sector as well as promised platform and digital services (Bucht & Hicks, 2018). This movement is being defined by multiple interrelated developments, including the integration of diverse technologies and the blurring of boundaries between the physical, digital, and biological domains (Grandinetti, 2020; Hollebeek et al., 2021). Among them are tools based on the application of artificial intelligence. Artificial Intelligence (AI) is increasingly recognised as a central force in shaping contemporary economic growth. Its influence extends across both microeconomic and macroeconomic dimensions. On the micro level, AI reshapes consumer behaviour and business practices by improving individual decision-making and streamlining internal operations. On the macro level, it drives productivity gains, transforms industrial structures, and fosters the rise of new engines of economic expansion (Wan et al., 2025, p. 22). Aloosi (2025) emphasises the importance of recognition that researchers and scholars have yet to reach a consensus on a single, universal definition of Artificial Intelligence. Generally, AI refers to technologies that replicate human cognitive functions, which is why it is often dubbed the "oil of the digital age" (Kirchner, 2024), highlighting its ability to imitate human thought processes and make independent decisions with significant real-world implications.

AI can be defined as “a set of behaviours and characteristics exhibited by computer programs that enable them to simulate human cognitive abilities and thinking patterns. Among the most significant features of AI is its ability to infer, learn, and respond to situations that were not explicitly programmed into the machine” (Ahmed, 2022, p. 17). The European Commission (2021) also outlines various examples of AI applications, such as chatbots, virtual assistants, facial recognition technologies, machine translation tools, data analysis powered by machine learning, as well as autonomous robots and drones. According to Coiera (2019), AI development can be broken down into three key phases, referred to as “miles.” The first phase involves gathering and preparing data, often called data cleaning. The second focuses on building and evaluating the performance of various algorithms based on that data. Finally, the third phase, known as the “last mile,” entails integrating the AI system into real-world settings and assessing its actual impact.

AI has rapidly permeated nearly all facets of contemporary life, reflecting a profound transformation in the way we interact with this emerging technology. No longer merely a tool of innovation, AI has become an integral element of daily functioning, augmenting human capabilities in both professional and personal contexts by offering efficient solutions to complex challenges and routine tasks. As AI technologies continue to advance, their transformative potential remains vast, provided their integration is approached with careful consideration of the ethical and moral implications that arise from their pervasive presence in human activity (Voronkova et al., 2024, p. 52). Artificial Intelligence (AI) has emerged as a key transformative force in both manufacturing and service sectors. Its growing integration is largely driven by the increasing need to process and utilise vast amounts of data effectively. AI-based solutions are being applied across a range of functions, including predictive maintenance, quality assurance, product customisation, supply chain coordination, inventory management, dynamic pricing, and customer support. By leveraging large-scale data analytics, AI facilitates more informed and autonomous decision-making, which is particularly vital for firms operating in highly competitive and globalised markets (Bonfiglioli et al., 2025, p. 1). Artificial Intelligence (AI) is increasingly integrated across various sectors of the economy and plays a determining role in optimising processes throughout all stages of business operations. Its contribution is particularly pronounced in fostering innovation, as AI facilitates the development of new products, services, and business models, enhances responsiveness to market changes, and supports more informed strategic decision-making. By enabling businesses to analyse complex data patterns, predict trends, and streamline workflows, AI catalyses sustained competitive advantage and long-term growth.

AI has the potential to significantly enhance economic performance by increasing operational efficiency, improving the quality of goods and services, and reducing production costs. It also enables firms to better understand consumer behaviour, identify emerging business opportunities, and mitigate financial risks. Nonetheless, AI introduces several economic challenges. It can lead to job displacement through automation, reinforce market concentration by favouring data-rich firms, and generate substantial costs related to system implementation and maintenance. Moreover, unintended consequences such as algorithmic bias and privacy violations may undermine public trust in AI-driven technologies (Kalai et al., 2024, p. 2). Regardless of the challenges, all this can become a new source of countries' comparative advantage.

3. COMPETITIVE ADVANTAGE BASED ON AI TECHNOLOGY

The Revealed Comparative Advantage (RCA) index was formulated by Bella Balassa in 1965. The index was constructed to measure a country's ability to compete with other countries in the world market for its products. In other words, the analytical significance of the index stems from its ability to assess an economy's competitiveness by comparing the performance of its products in specific sectors against those of other countries in the global marketplace (Živković, 2023, p. 76).

The purpose of the index is precisely to isolate the effects of comparative advantage, that is, to measure comparative advantage as precisely as possible. At the same time, it ignores the sources from which comparative advantage originates. The RCA index, often referred to as the Balassa Index (Balassa, 1965), serves as a standard measure of comparative advantage.

The methodology may be customised for particular technologies using the mathematical expression below (Chun, Hur & Hwang, 2024, p. 9):

$$RCA_{c,j,t} = \frac{patent_{c,j,t} / \sum_j patent_{c,j,t}}{\sum_c patent_{c,j,t} / \sum_c \sum_j patent_{c,j,t}} \quad (1)$$

Where c , j , and t represent the country, technology, and time, respectively.

One limitation of the RCA index lies in the range of its values. Specifically, the index exhibits asymmetry, as its values extend from 0 to positive infinity (Stellian & Danna-Buitrago, 2022, p. 130). A key issue with the RCA index is that the threshold value of 1 is commonly used to determine whether a country possesses a comparative advantage, despite not representing the mean value of the index. This asymmetry poses a methodological concern, which can be addressed by modifying the index to a range with clearly defined lower and upper bounds (Yu, Cai, & Leung, 2009, p. 270). One approach to addressing the asymmetry in the value distribution of the RCA index is the calculation of the Revealed Symmetric Comparative Advantage (RSCA) index. It is calculated according to the following formula (Zhang, Ebbers & Mulder, 2012, p. 207):

$$RSCA = \frac{RCA - 1}{RCA + 1} \quad (2)$$

The value of the index ranges from -1 to 1. A positive value of the index signifies the presence of a comparative advantage, whereas a negative value implies its absence.

4. ARTIFICIAL INTELLIGENCE AND REVEALED SYMMETRIC COMPARATIVE ADVANTAGE INDEX OF THE EUROPEAN COUNTRIES

The rise in AI-related patents highlights the growing impact of the technology. According to Szczepanski (2019), AI patent filings increased by an average of 6% per year from 2010 to 2015, surpassing the pace seen in other tech sectors. This trend indicates a broader acknowledgement of AI's importance across various industries, along with increased investments in research and development. Notably, fields such as machine learning, natural language processing, and robotics have seen significant patent activity, pointing to the wide-ranging uses of AI (Vijayakumar, 2021, p. 15). The EU regulates AI through a combined command-and-control and risk-based approach in the AI Act, linking strict requirements with transparency obligations that developers must implement and

oversight bodies enforce, while research increasingly advances fair, accountable, and transparent methods (Sloane & Wüllhorst, 2025).

The widespread use of AI across multiple sectors highlights its growing significance. AI patents play a vital role in advancing the technological sector in Europe and catalyse broader economic development (Kalai et al., 2024). Data on AI patent applications per one million inhabitants in European countries further illustrate the broad applicability and relevance of this technology (Table 1). The highest AI patent applications per one million people are in Luxembourg, with a score of 16.13 in 2019. With a good result, they also stand out from Germany, the UK, Finland, France and Denmark. The progress achieved by the leading countries in Europe, Luxembourg and Germany, in a relatively short period is interesting. This supports the observation that the adoption of AI has accelerated significantly since 2018. The Czech Republic and Ukraine have the lowest number of AI Patent applications per one million people in Europe from 2014 to 2019.

Table 1 AI patent applications per one million people in European countries

Country	2014	2015	2016	2017	2018	2019
Luxembourg	0.00	0.00	3.43	5.03	14.80	16.13
Germany	0.84	1.47	2.85	4.87	7.66	10.26
UK	1.08	1.41	2.85	4.16	6.10	6.29
Finland	2.01	2.01	1.46	3.63	7.25	6.16
France	0.51	0.54	1.01	1.49	2.81	3.36
Denmark	1.95	3.69	2.62	3.47	4.14	3.10
Spain	0.75	0.88	1.22	1.49	1.76	1.39
Netherlands	0.06	0.29	0.35	0.29	0.75	1.37
Italy	0.10	0.18	0.35	0.48	0.70	1.01
Norway	0.39	0.00	0.57	0.38	1.13	0.93
Lithuania	0.68	1.38	1.05	1.41	3.21	0.72
Austria	0.23	0.35	1.14	1.25	1.36	0.68
Serbia	0.14	0.14	0.28	0.28	0.71	0.57
Hungary	0.10	0.81	0.61	0.82	0.41	0.51
Poland	0.21	0.50	0.47	0.37	0.55	0.47
Bulgaria	0.00	0.14	0.00	0.42	0.57	0.43
Portugal	0.10	0.48	0.97	0.58	1.07	0.39
Romania	0.00	0.30	0.10	0.25	0.26	0.31
Turkey	0.03	0.05	0.10	0.13	0.21	0.29
Greece	0.90	0.18	0.37	1.30	0.84	0.28
Croatia	0.00	0.24	0.00	0.00	0.75	0.25
Switzerland	0.49	0.36	0.48	0.24	0.47	0.23
Belgium	0.00	0.00	0.18	0.18	0.70	0.17
Czech Republic	0.00	0.00	0.00	0.09	0.09	0.09
Ukraine	0.48	0.26	0.09	0.04	0.09	0.04

Source: Authors' calculation

Figure 1 shows the total number of AI patent applications per one million people in European countries from 2014 to 2019. There was a noticeable jump in 2018, reaching 58.39 applications per million. Table 1 shows the contribution of each country to the total number of European AI patent applications.

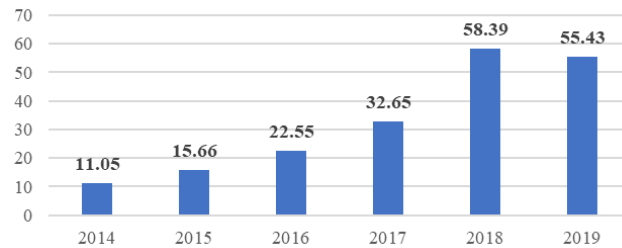


Fig. 1 AI patent applications per one million people in European countries
Source: Authors' calculation

In the leading European countries: Luxembourg, Germany, the UK, and France, in terms of the number of patents, the share of AI patents is growing from 2014 to 2019. In Finland and Spain, this is not the case. In these countries, there is a decrease in the share of AI patents in total patent applications (Figure 2).

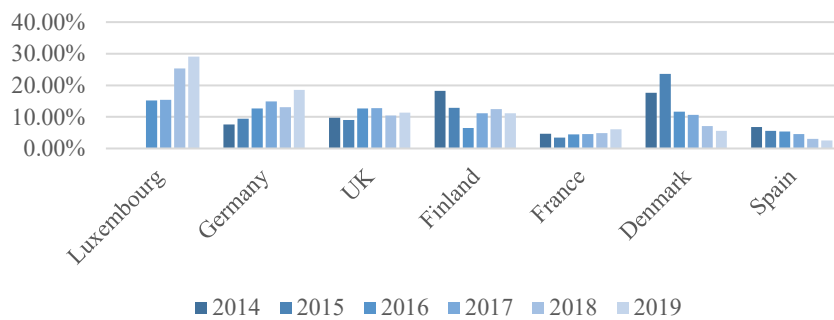


Fig. 2 Share of AI patents held by leading European countries in overall AI patent applications in Europe
Source: Authors' calculation

To assess whether the declining proportion of AI-related patents within the total number of patent applications in certain countries stems from a genuine reduction in the development and application of artificial intelligence technologies or whether it is influenced by other factors, such as an overall increase in patenting activity in other technological domains, it is informative to analyze the annual number of patent applications per million inhabitants. This indicator provides a broader context regarding innovation trends and patenting intensity at the national level, allowing for a more subtle interpretation of fluctuations in the relative share of AI patents. Germany has the most patent applications per million inhabitants, with over 500 patents per million inhabitants from 2014 to 2019 (Table 2).

Table 2 Annual patent applications per million people in European countries

Country	2014	2015	2016	2017	2018	2019
Luxembourg	230	225	246	262	250	189
Germany	595	580	589	578	562	561
UK	235	228	211	201	194	180
Finland	260	235	229	252	251	239
France	219	215	213	215	213	209
Denmark	244	257	271	258	218	232
Spain	64	60	59	47	33	27
Netherlands	136	130	134	131	123	128
Italy	141	146	146	143	148	155
Norway	215	222	234	218	204	179
Lithuania	42	35	33	29	29	32
Austria	245	255	238	236	231	233
Serbia	28	25	27	24	23	24
Hungary	55	58	63	51	42	44
Poland	104	123	112	103	111	102
Bulgaria	30	39	32	29	26	27
Portugal	69	89	70	63	64	68
Romania	48	49	51	56	56	45
Turkey	62	68	79	102	88	95
Greece	60	51	56	46	40	33
Croatia	40	41	43	37	30	49
Switzerland	181	178	175	158	151	160
Belgium	79	84	93	88	78	79
Czech Republic	86	83	75	75	64	72
Ukraine	53	50	49	50	47	47

Source: Authors' calculation

Based on the presented data, the Revealed Symmetric Comparative Advantage (RSCA) index was calculated. Table 3 shows the results of the RSCA index, which presents the existence of a comparative advantage resulting from the application of AI. It can be noted that there are many countries and many years when the comparative advantage from this source was not present. Only four countries have an AI comparative advantage during the entire observed period: the UK, Spain, Lithuania, and Serbia. Interestingly, although these countries are at different stages of economic development, the disparity in AI-based comparative advantage between more and less developed economies appears to be relatively minor. Also, regardless of the large number of AI patent applications in Germany and France, these countries do not have a comparative advantage because the value of the RSCA index is negative. In most European countries, there is no comparative advantage based on the application of AI. The comparative advantage mostly existed in certain years, but it was not enough for its long-term sustainability.

Table 3 RSCA index for European countries from 2014 to 2019

Country	2014	2015	2016	2017	2018	2019
Luxembourg	-1.0000	-1.0000	0.3714	0.3399	0.5372	0.6633
Germany	-0.3795	-0.2733	-0.1383	-0.0577	-0.1333	0.0286
UK	0.1884	0.1640	0.3576	0.3727	0.2764	0.3384
Finland	0.4225	0.3164	-0.0013	0.2073	0.2368	0.1975
France	-0.1481	-0.2775	-0.1482	-0.1543	-0.1493	-0.0359
Denmark	0.4361	0.5275	0.2040	0.1742	0.0317	-0.1277
Spain	0.5775	0.5351	0.5278	0.5404	0.4990	0.4975
Netherlands	-0.7535	-0.3313	-0.4198	-0.6207	-0.4902	-0.2348
Italy	-0.6313	-0.5654	-0.4545	-0.4761	-0.5806	-0.4522
Norway	-0.2674	-1.0000	-0.4481	-0.6888	-0.5258	-0.5375
Lithuania	0.6753	0.7975	0.6654	0.6743	0.7226	0.1314
Austria	-0.5395	-0.5278	-0.1433	-0.2821	-0.5034	-0.7109
Serbia	0.2288	0.1154	0.2374	0.1045	0.2679	0.1579
Hungary	-0.2663	0.5174	0.2047	0.2592	-0.2922	-0.1969
Poland	-0.2170	-0.0442	-0.2073	-0.4495	-0.5649	-0.5788
Bulgaria	-1.0000	-0.1060	-1.0000	0.2099	0.1031	-0.0406
Portugal	-0.3682	0.0968	0.3687	-0.0135	-0.0320	-0.5015
Romania	-1.0000	0.1591	-0.5305	-0.3587	-0.5867	-0.4298
Turkey	-0.7328	-0.7159	-0.6694	-0.7625	-0.7638	-0.6996
Greece	0.6540	-0.1144	0.0166	0.4985	0.0818	-0.3412
Croatia	-1.0000	0.1372	-1.0000	-1.0000	0.1676	-0.5440
Switzerland	-0.0738	-0.3742	-0.3995	-0.7232	-0.7027	-0.8463
Belgium	-1.0000	-1.0000	-0.5351	-0.6444	-0.3302	-0.7784
Czechia	-1.0000	-1.0000	-1.0000	-0.7748	-0.8537	-0.8650
Ukraine	0.4853	0.0787	-0.5536	-0.8440	-0.8060	-0.9061

Source: Authors' calculation

Artificial intelligence (AI) offers a novel perspective in understanding the determinants of comparative advantage. Unlike traditional sources of comparative advantage, which are often closely tied to economic growth, industrial capacity, or investment in physical production processes, AI represents a knowledge-driven resource. It relies primarily on human capital, expertise, and innovative thinking, rather than on material or financial inputs. As such, it opens opportunities for less developed countries to differentiate themselves and compete globally, despite limitations in traditional economic indicators.

5. CURRENT TRENDS IN AI ADOPTION

This study covered period from 2014 to 2019 because of data availability. However, this is the area where innovation and development are rapid. This is the reason why it is important to constantly follow the development of the AI at micro level, which consequently affects the comparative advantage of industries and the national comparative advantage. Abdullah et al. (2025) find that AI applications contribute to 25–30% improvement in decision-making speed and accuracy, a 10–20% increase in customer engagement, and a 15% reduction in operational costs. Most of these processes can be automated (Pu et al., 2025). This was achieved by machine learning, natural language processing, robotic process automation and decision intelligence systems (Abdullah et al., 2025). Artificial intelligence is a tool that helps

managers to create competitive advantage in marketing, finance, operations, human resources, and information management (Ahmed & Ahmed, 2024). Adoption of AI improves the achievement of competitive advantage in the business sector, especially of enterprises. AI application has simplified everyday tasks by enabling companies to provide a variety of digital endpoint services to their customers (Ayyash & Mousa, 2025). However, large companies have recorded the highest use of artificial intelligence, while small and medium-sized enterprises are less prepared for it (Stan et al., 2025).

Senadjki et al. (2023) find positive significant relationship between AI (awareness, empowerment, implementation) and competitiveness. Jeon (2025) studied relationship between AI capabilities and national competitiveness and concluded that infrastructure and research capacity are the most important determinants of competitiveness. According to Voronkova et al. (2024), AI adoption can improve national resilience, economic stability, and a country's competitive position on the global market. Countries that prioritize digital adoption, infrastructure development, and innovation typically rank higher on international competitiveness indexes (Jarzębowski et al., 2024). Digitalization and tech innovation play a crucial role in enhancing competitiveness and sustainable development in EU countries, offering a strong basis for shaping public policies aimed at speeding up innovation environment and digital transformation. For this reason, there is a need to formulate integrated public policies that promote the development of digital skills and the strengthening of innovation ecosystems (Doroiman & Sirghi, 2025).

Application of AI requires regulation of ethical issues. The key role in this issue is played by governments. New forms of regulation of the digital economy are needed that will prevent further growth in market concentration, ensure adequate data protection and privacy, and help share the benefits of productivity growth through a combination of profit sharing and taxation of (digital) capital (Ernst et al., 2019). A combination of macroeconomic, social, and institutional governance factors provides strong support for the design of robust policies that promote the implementation of AI at the government level, along with mechanisms to stimulate economic expansion, public investment, and foreign capital inflows (Socol et al., 2025).

6. CONCLUDING REMARKS

Considering the significant potential of artificial intelligence (AI) and its applications across various domains, as evidenced by the number of patent applications, AI can be regarded as a contemporary source of comparative advantage for countries. This perspective offers valuable insights into how a country can distinguish itself on a global scale. In Europe, relatively few countries achieve a comparative advantage in this field. Luxembourg has held the highest comparative advantage in recent years, followed by the UK, while Spain also records a high RSCA index. A notable finding of this research is that both Lithuania and Serbia have maintained a comparative advantage in AI applications throughout the entire observation period. Of course, to confirm such a conclusion, we should have a longer time series, which is not the case here. The data is only available until 2019, which is why this research period was chosen. It is also a limitation of the research. A longer time series would provide insight into recent trends in the application of AI, given that the field is undergoing drastically rapid changes. Nevertheless, the analysis in the selected period also provides significant results on the comparative advantage of the selected European countries resulting from the progress of AI. This suggests that the

persistence of comparative advantage in this domain is not solely determined by the level of economic development. This means that all countries have the same starting points for AI innovations. There are no more or less innovative countries from the perspective of economic development. All countries have the same chance to be innovative in AI technology, and they have to seize it. Policy makers have to establish the framework in which AI innovation will be easier to launch. As a result of a higher number of AI patents, countries may expect higher economic growth. Consequently, future research could focus on examining the relationship between economic growth and the attainment of comparative advantage in AI.

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TRENDVI PRIMENE AI I KOMPARATIVNA PREDNOST U EVROPSKIM ZEMLJAMA PRE 2020. GODINE

Napredne tehnologije, a naročito primena AI se razvijaju velikom brzinom i doprinose reformi privrede na mikro i makro nivou. Istovremeno, s obzirom na veliki potencijal koji ima, primena AI može postati značajan izvor komparativne prednosti zemlje. U radu se istražuje da li su evropske zemlje dostigle komparativnu prednost koja potiče iz primene AI u periodu od 2014. do 2019. godine. Komparativna prednost je merena pomoću RSCA indeksa čije pozitivne vrednosti ukazuju na njeno postojanje. Parametar koji je korišćen za izračunavanje ovog indeksa je broj prijavljenih patenata u vezi primene AI. Rezultati su pokazali da mali broj evropskih zemalja ima komparativnu prednost zasnovanu na AI, ali da su u toj grupi zemlje na različitom nivou ekonomskog razvoja. To upućuje na zaključak da razvijenost zemlje nije ključna za razvijanje inovativnih ideja zasnovanih na primeni AI.

Ključne reči: *veštačka inteligencija, komparativna prednost, RSCA, Evropa*