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ЕКОНОМИКА

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МЕЂУНАРОДНИ ЧАСОПИС
ЗА ЕКОНОМСКУ ТЕОРИЈУ И ПРАКСУ И ДРУШТВЕНА ПИТАЊА

ЕКОНОМИКА

Часопис излази четири пута годишње Година LXXI, X-XII 2025, број 4

ИЗДАВАЧ: Друштво економиста "Економика" Ниш
СУИЗДАВАЧИ: Институт за економику пољопривреде - Београд, Економски факултет у Суботици, Друштво економиста Ниша, Факултет за примењени менаџмент економију и финансије МЕФ - Београд

1. Часопис "Економика" покренут је јула 1954. године и под називом " Нишки привредни гласник" излазио је до јуна 1957. године, а као "Привредни гласник" до краја 1969. године. Назив "Наука и пракса" носио је закључно са бројем 1/1973. год. када добија назив "Економика" који и данас има.

2. Часопис су покренули Друштво економиста Ниша и Друштво инжињера и техничара Ниша (остало као издавач до краја 1964. године). Удружење књиговођа постаје издавач почев од броја 6-7/1958. године. Економски факултет у Нишу на основу своје одлуке броја 04-2021 од 26.12.1991. године постао је суиздавач "Економике". Такође и Економски факултет у ПриШтини постао је суиздавач од 1992. године. Почев од 1992. године суиздавач "Економике" је и Друштво за маркетинг региона Ниш. Као суиздавач "Економике" фигурирали су у току 1990-1996. године и Фонд за научни рад општине Ниш, Завод за просторно и урбанистичко планирање Ниш и Корпорација Винер Брокер Ниш.

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FACTORS OF PRODUCT INNOVATION AMONG EARLY-STAGE ENTREPRENEURS IN SOUTHEAST EUROPE: AN EMPIRICAL ANALYSIS OF GEM DATA

Abstract

Purpose: The paper aims to examine the determinants of product and service innovation among early entrepreneurs in Southeast Europe with a focus on technological equipment, business ownership, expected growth and internationalization.

Methodology: The analysis was conducted using the 2020 GEM database, using ordinal logistic regression. In the sample, 343 valid answers were identified, focused exclusively on TEA entrepreneurs of Southeastern Europe. The dependent variable refers to the degree of innovation of the product or service, and the model included the innovation of the technology used, ownership structure, expected growth and internationalization.

Findings: The use of innovative technologies and processes is a strong and statistically significant predictor of product and service innovation. Entrepreneurs who use technologies that are new at the national and global level have a significantly greater advantage to bring innovative products and services. Also, entrepreneurs who expect greater growth of the company show a higher level of innovation compared to those with lower growth expectations. The variables of ownership structure and business internationalization did not show a statistically significant impact on product and service innovation.

Originality/value: The work brings empirical insight into the factors that shape the innovativeness of products and services in the early stages of entrepreneurship, which represents a relatively poorly researched area in the domestic context.

Practical implications: The findings can be used by political decision-makers to shape innovation in the early stages of entrepreneurship, especially in the domain of fostering and introducing globally new technologies.

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Limitations: The research is limited by the available data from one year, based on the attitudes of the respondents. Future research could include longitudinal data and qualitative methods to confirm these findings.

Key words: *Innovation, ownership, business growth, internationalization, GEM.*

JEL classification: *L26*

ФАКТОРИ ИНОВАЦИЈЕ ПРОИЗВОДА МЕЂУ ПРЕДУЗЕТНИЦИМА У РАНИМ ФАЗАМА У ЈУГОИСТОЧНОЈ ЕВРОПИ: ЕМПИРИЈСКА АНАЛИЗА ПОДАТАКА GEM-а

Апстракт

Сврха: Циљ рада је испитивање детерминанти иновација производа и услуга међу раним предузетницима у Југоисточној Европи са фокусом на технолошку опремљеност, власништво над предузећем, очекивани раст и интернационализацију.
Методологија: Анализа је спроведена коришћењем GEM базе података из 2020. године, применом ординалне логистичке регресије. У узорку је идентификовано 343 валидна одговора, фокусирана искључиво на TEA предузетнике Југоисточне Европе. Зависна променљива се односи на степен иновативности производа или услуге, а модел је обухватио иновативност коришћене технологије, структуру власништва, очекивани раст и интернационализацију.
Резултати: Употреба иновативних технологија и процеса је снажан и статистички значајан предиктор иновација производа и услуга. Предузетници који користе технологије које су нове на националном и глобалном нивоу имају значајно већу предност да донесу иновативне производе и услуге. Такође, предузетници који очекују већи раст компаније показују виши ниво иновативности у поређењу са онима са нижим очекивањима раста.
Варијабле структура власништва и интернационализација пословања нису показале статистички значајан утицај на иновације производа и услуга.
Оригиналност/вредност: Рад доноси емпиријски увид у факторе који обликују иновативност производа и услуга у раним фазама предузетништва, што представља релативно слабо истражену област у домаћем контексту.
Практичне импликације: Налази могу бити коришћени од стране политичких доносилаца одлука за обликовање иновација у раним фазама предузетништва, посебно у домену неговања и увођења нових технологија на глобалном нивоу.
Ограничења: Истраживање је ограничено доступним подацима из једне године, на основу ставова испитаника. Будућа истраживања би могла да обухвате лонгитудиналне податке и квалитативне методе како би се потврдили ови налази.

Кључне речи: Иновације, власништво, раст пословања, интернационализација, GEM.

Introduction

Entrepreneurs are actors of society who contribute significantly to economic growth (Munyo & Veiga, 2024). Those who are in the early stages of the development of entrepreneurial ventures stand out, because their activities have a positive effect in developed, but also in developing countries (Ivanović-Djukić et al., 2018). Their actions are characterized by a high level of risk and uncertainty, which enables them to create the conditions for creating innovations that can change market dynamics. The innovativeness of their products is a vital success factor. Innovations allow them to stand out from the competition, secure first customers and attract investors. In the region of Southeast Europe, which consists of economies facing structural challenges, the innovations of young companies play an even more significant role in increasing competitiveness and modernizing the market. Although the importance of innovation for economic growth has been confirmed and widely recognized in earlier research (Cameron, 1996; Hasan & Tucci, 2010; Ivanović-Djukić et al., 2018), empirical research that focuses on specific factors that shape the innovativeness of products and services, especially in the context of SEE, remains limited (Abazi-Alili et al., 2014). There is a clear need for a deeper understanding of the mechanisms through which certain aspects of business can contribute to the development of innovative products and services. This paper aims to examine how technological equipment, ownership structure of the company, expectations regarding growth and internationalization of business influence the innovativeness of entrepreneurs in the early stages of development in SEE. The analysis is based on data from the Global Entrepreneurship Monitor (GEM) database for 2020. The structure of the paper includes the theoretical framework and development of hypotheses, methodological part, analysis of results, discussion and concluding considerations with practical implications.

Theoretical background

Entrepreneurs are often considered in the literature as foci of innovation (Love & Roper, 2015; Audretsch, 2002, Janošik *et al.*, 2024). In terms of innovative activities, their advantages are reflected in the ability to make quick decisions, willingness to take risks and flexibility in responding to market opportunities, while limitations are manifested in the scope and availability of the necessary resources. Functioning in conditions of limited formalization, within fluid business models allows them to experiment with new ideas faster (Blank & Dorf, 2020). Such adaptability and openness encourage an environment suitable for innovation, especially in situations of a clearly observed market gap that is not satisfied by existing solutions (Nambisan, 2017). In this context, innovation does not depend predominantly on resources, but on the ability to identify and exploit opportunities - which is the essence of entrepreneurial behavior (Shane & Venkataraman, 2000; Matić, et al 2023; Ognjenović, 2024). Early entrepreneurs can often be motivated by the need to offer something different to the market (Global Entrepreneurship Monitor, 2020), so innovation becomes not only a strategic advantage, but also a necessity for survival and growth (Estay et al., 2013). Innovative activities of entrepreneurs in the early stages of the development of their ventures are often associated with higher growth rates and probability of survival (Huergo & Jaumandreu, 2004;). In regions with institutional

challenges, such as Southeast Europe, innovative entrepreneurial firms become catalysts for change and modernization of the economy (Abazi-Alili et al., 2014; Bylund & McCaffrey, 2017). Their ability to harmonize local knowledge and global practices makes them potential sources of industry transformation and the opening of new markets (Radaković, 2024). Innovative outcomes are influenced by a range of interrelated factors. Their understanding is important for the theoretical mapping of innovation processes in entrepreneurship, but also for the formulation of practical recommendations aimed at strengthening innovation capacities. The identification of relevant factors that contribute to the development of innovations in specific stages of company development is an important research challenge.

Technological capacity

Digital technologies have been the source of many innovations that have transformed economies (Jiao et al., 2025). Application of advanced technological solutions (blockchain, artificial intelligence, IoT) significantly raise the level of innovation of products and services (Grujić & Vojinović, 2024; Omari et al., 2025; Jiao et al., 2025). Omari et al. (2025) showed that the financing of R&D activities by entrepreneurs contributes to the appearance of new products on the market. Technological diversification is posited as a mediator between entrepreneurial orientation and product and service innovation (Lin et al., 2023; Matić et al., 2025). Small businesses can profit from the use of digital tools (in which we can include affordable software, mobile applications with specific purposes in business), which help them to create or market their products and services more efficiently (Danil et al., 2025). The development, adoption and spread of new technologies leads to a strengthening of competitiveness, because it enables faster recognition and integration of external knowledge into one's own innovations (Cuevas-Vargas et al., 2022). As markets accelerate, firms that are more digitally developed have a greater advantage in the speed of response to external challenges, which directly reflects on innovation (Guo et al., 2023). Based on the previous consideration, H1 hypothesis is set:

H1: The technological equipment of entrepreneurs in the early stages of enterprise development has a positive effect on the innovativeness of products and services.

Ownership structure

Concentration of ownership in the hands of an individual can be associated with greater agility and a greater focus on innovation. When an entrepreneur controls the company independently, without coordination with partners, he can react more quickly to market changes, adapt to customer needs and direct resources towards the development of new products and services. In such circumstances, there is greater freedom when setting goals, because there are fewer bureaucratic obstacles and conflicts of interest. An owner who independently participates in the business is more strongly motivated and focused on growth, while multiple entrepreneurs in the ownership structure usually have a short-term orientation (Ma et al., 2022). A multi-participant structure may be more passive towards change, while an individual is more prone to risk and innovation. Henselek et al. (2023)

show that ventures with fewer employees per founder are more flexible. Decisions are made faster and innovative initiatives are launched more easily. The innovative process slows down with an increase in the number of employees per owner, because the founder loses part of his direct influence (Henselek et al., 2023). Concentrated ownership control combined with R&D investments improves the performance of companies (Chatterjee & Bhattacharjee, 2021). Theoretically, we conclude that a high degree of ownership control by early entrepreneurs can be a factor that encourages innovation, and accordingly the following hypothesis is put forward:

H2: The concentration of ownership control of entrepreneurs in the early stages of venture development has a positive effect on product and service innovation.

Expected growth

Entrepreneurs who expect the growth of their own enterprise treat innovation as a tool to achieve their expectations. Entrepreneurial aspirations stimulate the creation of new jobs and encourage innovation (Khefacha et al., 2024). Market expansion and global competition raise growth expectations, and this increases the pressure on entrepreneurs to innovate their products and services to remain competitive (Castaño et al., 2016). Poblete (2022) shows in his research that high entrepreneurial growth ambitions have a positive effect on the innovative behavior of company owners. He came to identical findings in 2018, when he pointed out that entrepreneurs who introduce innovative products or services have more ambitious growth plans (Poblete, 2018). In other words, entrepreneurs who are ambitious innovate more, and those innovators strive for greater growth. Močnik & Širec (2016) confirmed in their work that the introduction of product and service innovations raises the expectations of company growth. This result is particularly prominent and significant for developed European countries, while it was weaker in Southeastern economies. In summary, it is theoretically and empirically justified to assume that entrepreneurs with higher growth expectations invest more often in product and service innovations, and therefore the following hypothesis is put forward:

H3: Greater growth expectations of entrepreneurs in the early stages of venture development have a positive effect on the innovativeness of products and services.

Internationalization

The innovativeness of entrepreneurs in the early stages of the development of their ventures is often linked to their export orientation. Entrepreneurs who are oriented towards exports and foreign markets have a special innovation profile. Entering the foreign market exposes them to strong competition and new knowledge, which at the same time enables, but also forces them to innovate their products and services (Stojanović et al., 2023). Businesses that participate with high intensity in foreign markets are more easily able to develop new products and overcome innovation barriers (Love & Ganotakis, 2013). Ramos-Hidalgo et al (2022) confirm that innovation plays a vital role in internationalization because it enables internal changes and adaptation of resources, which is necessary for sustainable growth in foreign markets. SMEs need to

constantly expand their markets through exports while innovating in order to remain competitive, where the ability to learn is a key advantage to conquer new markets (Harrison & Pooe, 2022). Exporters who introduce organizational innovations in parallel significantly improve innovation performance after entering foreign markets (Juergensen et al., 2024). These findings suggest that export orientation can stimulate product and service innovation, and therefore the following hypothesis is put forward:

H4: Internationalization (organizational orientation) of entrepreneurs in the early stages of venture development has a positive effect on the innovativeness of products and services.

Methodology

The research was conducted by analyzing data from the GEM Adult Population Survey (APS) database from 2020, with a focus exclusively on respondents from Southeast European countries who are classified as TEA entrepreneurs (entrepreneurs at the start-up stage and start-up companies). The total number of valid responses after filtering was 343, while the total sample size was 6000, with the remaining responses discarded due to missing data or unfocused categories.

Ordinal logistic regression was used for statistical processing, with the aim of identifying the importance of individual predictors on the level of product innovation. Variables related to the characteristics of entrepreneurs and their firms are included in the model, while the gender variable is included as a control variable, to neutralize the potential influence of demographic differences on perceived or actual product innovation.

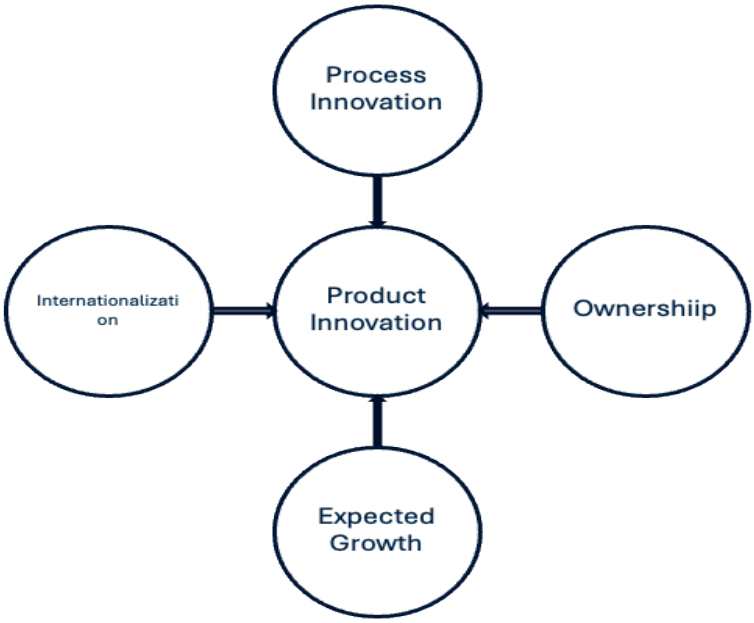
The dependent variable, as well as all independent variables, are shown in the following table with the response categories used in the model.

Table 1: *Variable description*

Variable name	Variable description	Response categories and codes
Product innovation (dependent variable)	Are the products/services new to the market?	1 – Not new, 2 – New to local market, 3 – New to the country, 4 – New to the world
Technological capacity	Are the technologies / procedures used new?	1 – Not new, 2 – New to local market, 3 – New to the country, 4 – New to the world
Ownership	Is the business partially owned by the employer?	0 – No, 1 – Yes
Growth expectation	Number of jobs the entrepreneur expects to create	1 – No employees, 2 – 1 to 5, 3 – 6 to 19, 4 – 20+
Internationalization	Is more than 25% of revenue generated abroad?	0 – No, 1 – Yes
Gender *(control variable)*	Gender of the respondent?	1 – Male, 2 – Female

Source: Authors' analysis

Figure 1: *Conceptual model*



Source: Authors' analysis

Research results and discussion

The model proved to be significant (Chi-Square = 116.033, df = 9, $p < 0.001$), which confirms that the included predictors contribute to explaining the variance in the dependent variable. The model fit statistics indicate that there is no significant difference between the model and the observed data (Deviance $\chi^2 = 222.715$, df = 198, $p = 0.110$), which indicates a good fit of the model. The value of the pseudo-R-squared coefficient further illuminates the explanatory power of the model. The Nagelkerke R^2 is 0.342 and is an adjusted version of the Cox and Snell coefficient. This value implies that the model explains about 34% of the variance of the dependent variable. McFadden's R^2 is 0.185. In the context of logistic and ordinal regression, this value indicates a good ability of the model to distinguish different levels of the dependent variable, since values between 0.2 and 0.4 are often considered very satisfactory in this type of analysis.

The thresholds between the categories of the dependent variable (thresholds) show the locations that determine the transitions between the levels of innovation: "not new", "new in the place", "new in the country", and "new in the world". Their values are all statistically significant, indicating that the categories are properly ordinally distributed and that the model successfully discriminates between them.

Table 2: *Parametric findings*

Parameter Estimates								
		Estimate	Std. Error	Wald	df	Sig.	95% Confidence Interval	
							Lower Bound	Upper Bound
Threshold	[teanewprod = 1]	-5,062	1,013	24,957	1	0	-7,048	-3,076
	[teanewprod = 2]	-3,78	0,996	14,405	1	0	-5,732	-1,828
	[teanewprod = 3]	-2,143	0,953	5,054	1	0,025	-4,011	-0,275
Location	[teanewproc=1]	-5,369	0,897	35,802	1	0	-7,127	-3,61
	[teanewproc=2]	-3,373	0,912	13,672	1	0	-5,161	-1,585
	[teanewproc=3]	-2,878	0,904	10,129	1	0,001	-4,65	-1,105
	[teanewproc=4]	0a	.	.	0	.	.	.
	[teayyspon=0]	-0,063	0,278	0,051	1	0,822	-0,607	0,482
	[teayyspon=1]	0a	.	.	0	.	.	.
	[teayyj5y=1]	-0,576	0,548	1,105	1	0,293	-1,651	0,498
	[teayyj5y=2]	-0,929	0,431	4,635	1	0,031	-1,774	-0,083
	[teayyj5y=3]	-0,811	0,46	3,104	1	0,078	-1,712	0,091
	[teayyj5y=4]	0a	.	.	0	.	.	.
	[teaexpst=0]	-0,337	0,325	1,077	1	0,299	-0,974	0,3
	[teaexpst=1]	0a	.	.	0	.	.	.
	[gender=1]	-0,413	0,272	2,307	1	0,129	-0,946	0,12
	[gender=2]	0a	.	.	0	.	.	.
Link function: Logit.								
a This parameter is set to zero because it is redundant.								

Source: Authors' analysis

Ordinal regression parameter estimates indicate the effects that the independent variables have on the likelihood that respondents report a higher level of product innovation. The interpretation is done in relation to the reference categories that are automatically defined by SPSS.

For the variable novelty of used technologies or procedures (teanewproc), the results show that compared to the reference category "new technologies at the world level", respondents who use technologies that are not new (Estimate = -5.369, $p < 0.001$), that are new only at the local level (Estimate = -3.373, $p < 0.001$), or new at the national level (Estimate = -2.878, $p = 0.001$) are significantly less likely to report a higher level of product innovation. We can interpret these negative coefficients so that the use of less innovative technologies statistically significantly reduces the chance of an entrepreneur developing an innovative product, which is in line with expectations. The obtained results confirm the previous research, according to which technological equipment and innovation are strongly connected. Our results are consistent with the results of Jiao et al (2025) and Omari et al (2025), according to which the application of advanced technologies directly contributes to the development of innovations. The agreement on

the importance of technological equipment for competitiveness and innovation coincides with the findings of Cuevas-Vargas et al. (2022) and Dinesh (2021). Based on the above, we conclude that hypothesis H1 is confirmed.

The variable indicating whether the firm is partially owned by the employer (teayyspon) did not show a statistically significant effect (Estimate = -0.063, p = 0.822). This result suggests that the ownership structure in this form does not significantly affect the perception of product innovation among early entrepreneurs. This finding indicates that the hypothesis H2 is rejected. We find similar results in Choi et al (2011), who in the context of Chinese firms found that the concentration of ownership is not statistically significantly related to innovation. Likewise, Dinesh (2021) points out that entrepreneurial ownership, although more pronounced in some contexts such as India, does not necessarily lead to higher levels of product innovation. This instability of the relationship may be the result of institutional limitations and low support for innovation, which is often the case in the countries of Southeast Europe.

When it comes to the expected growth of the entrepreneurial venture in the next five years (teayyj5y), the results show that entrepreneurs who expect between 6 and 19 new jobs are significantly less likely to report highly innovative products compared to those who expect more than 20 jobs (Estimate = -0.929, p = 0.031). The category 1–5 jobs (Estimate = -0.576, p = 0.293) as well as the category 6–19 (Estimate = -0.811, p = 0.078) have a similar negative, but marginally significant effect, although their statistical significance is not at a significant level. These findings could indicate that only more ambitious entrepreneurs (those who plan large growth) tend more towards more innovative products. These findings are consistent with the work of Castaño et al (2016), in which they emphasize that high growth aspirations create the need and pressure to introduce innovations. Empirically, similar results are reached by Poblete (2022), whose research shows that ambitious entrepreneurs more often introduce innovations as part of a growth strategy. In the context of Southeast Europe, where institutional factors can weaken the intensity of the relationship (Močnik & Širec, 2016), the basic trend remains. The findings of this research confirm hypothesis H3, as the most ambitious entrepreneurs see product innovation as a key part of their strategy.

The international orientation variable (teaexpst) did not prove to be a statistically significant predictor (Estimate = -0.337, p = 0.299), which suggests that export orientation in this model is not directly related to the level of product innovation, at least not in a statistically significant way. Based on this, hypothesis H4 was rejected.

Finally, the gender variable, used as a control, has a negative but statistically insignificant effect (Estimate = -0.413, p = 0.129). This indicates that there is no significant difference between men and women when it comes to the reported level of product innovation, after controlling for the other variables in the model.

Conclusion

Within this research, the influence of four determinants that can affect the innovativeness of products and services among early entrepreneurs in Southeast Europe was examined. The issues are technological equipment, ownership structure, expected business growth and internationalization. By applying ordinal logistic regression to a

sample of 343 TEA entrepreneurs from the GEM APS database for 2020, it was confirmed that the level of technological equipment is the most significant factor of innovation. Entrepreneurs who use technology that is new at the national and global level are many times more likely to develop innovative products and services.

Also, entrepreneurs with ambitious growth expectations (planning to create more than 20 jobs in the next five years) have been shown to have a higher level of innovation compared to those with moderate or more modest growth plans. This finding indicated a close intertwining of growth strategies and innovation activities in the early stages of the development of entrepreneurial ventures.

On the contrary, the variables describing the concentration of ownership control and the internationalization of business did not give statistically significant results, which suggests that these dimensions, in the context of early entrepreneurship in Southeast Europe and within the analyzed data, do not play a decisive role in shaping the innovation of products and services.

This paper contributes to the theoretical literature by providing empirical evidence on the central role of technological equipment and entrepreneurial aspirations in the growth of innovation at the level of entrepreneurs who are in the initial stages of developing their businesses. At the same time, it opens a discussion about the weaker influence of ownership and internationalization factors, which may be a consequence of the specific institutional circumstances of the observed region.

From the point of view of practical application, the results point to the need to direct support towards the faster adoption of globally new technologies among early entrepreneurs, as well as to encourage ambitious plans through facilitation of employment and market expansion. Programs of state grants, subsidies and advisory services should be aimed at technological education and development, but also at networks that connect entrepreneurs with foreign partners and investors.

The limitations of the work are reflected in the fact that the database represents a cross-section from the year 2020, which is based on the respondents' assessment, which may affect the bias in the perception of their own innovativeness. Future research could include longitudinal analyses, to follow the dynamics of innovation over time, use qualitative methods for a deeper understanding of the decision-making process, expand the model with additional factors (institutional quality, access to capital) and comparative analyzes between countries and regions.

References

Abazi-Alili, H., Ramadani, V., & Gerguri-Rashiti, S. (2014, November). Determinants of innovation activities and their impact on the entrepreneurial businesses performance: empirical evidence from Central and South Eastern Europe. In *REDETE Conference Proceedings.*

Audretsch, D. B. (2002). The dynamic role of small firms: Evidence from the US. *Small business economics, 18*, 13-40.

Blank, S., & Dorf, B. (2020). *The startup owner's manual: The step-by-step guide for building a great company.* John Wiley & Sons.

Bylund, P. L., & McCaffrey, M. (2017). A theory of entrepreneurship and institutional uncertainty. *Journal of Business Venturing, 32*(5), 461-475.

Cameron, G. (1996). *Innovation and economic growth* (No. 277). London School of Economics and Political Science. Centre for Economic Performance.

Castaño, M. S., Méndez, M. T., & Galindo, M. Á. (2016). Innovation, internationalization and business-growth expectations among entrepreneurs in the services sector. *Journal of Business Research, 69*(5), 1690-1695.

Chatterjee, M., & Bhattacharjee, T. (2021). Ownership concentration, innovation and firm performance: empirical study in Indian technology SME context. *South Asian Journal of Business Studies, 10*(2), 149-170.

Choi, S. B., Lee, S. H., & Williams, C. (2011). Ownership and firm innovation in a transition economy: Evidence from China. *Research policy, 40*(3), 441-452.

Cuevas-Vargas, H., Cortés-Palacios, H. A., Leana-Morales, C., & Huerta-Mascotte, E. (2022). Absorptive capacity and its dual effect on technological innovation: a structural equations model approach. *Sustainability, 14*(19), 12740.

Danil, L., Jahroh, S., Syarief, R., & Taryana, A. (2025). Technological Innovation in Start-Ups on a Pathway to Achieving Sustainable Development Goal (SDG) 8: A Systematic Review. *Sustainability* (2071-1050), 17(3).

Dinesh, K. K. (2021). Strategic innovation and entrepreneurial ownership: an analysis using GEM data and fuzzy simulation. *Benchmarking: An International Journal, 28*(10), 2896-2915.

Estay, C., Durrieu, F., & Akhter, M. (2013). Entrepreneurship: From motivation to start-up. *Journal of international Entrepreneurship, 11*(3), 243-267.

Global Entrepreneurship Monitor. (2020, March 3). *GEM 2019/2020 Global Report Press Release: Entrepreneurs worldwide motivated to make a difference.* https://www.gemconsortium.org/news/gem-2019%2F2020-global-report-press-release%3A-entrepreneurs-worldwide-motivated-to-make-a-difference

Grujić, M., & Vojinović, Ž. (2024). Investing in blockchain technologies and digital assets: accounting perspectives. *Anali Ekonomskog fakulteta u Subotici, 60*(52), 119-136.

Guo, R., Yin, H., & Liu, X. (2023). Coopetition, organizational agility, and innovation performance in digital new ventures. *Industrial Marketing Management, 111*, 143-157.

Harrison, G. J., & Pooe, D. (2022). Modelling the antecedents for export orientation, innovation capacity and performance for South African manufacturing SMEs. *Acta Commercii, 22*(1), 1-12.

Hasan, I., & Tucci, C. L. (2010). The innovation–economic growth nexus: Global evidence. *Research policy, 39*(10), 1264-1276.

Hensellek, S., Kleine-Stegemann, L., & Kollmann, T. (2023). Entrepreneurial leadership, strategic flexibility, and venture performance: Does founders' span of control matter?. *Journal of Business Research, 157*, 113544.

Huergo, E., & Jaumandreu, J. (2004). Firms' age, process innovation and productivity growth. *International Journal of Industrial Organization, 22*(4), 541-559.

Ivanović-Djukić, M., Lepojević, V., Stefanović, S., van Stel, A., & Petrović, J. (2018). Contribution of Entrepreneurship to Economic Growth: A Comparative Analysis of South-East Transition and Developed European Countries. *International Review of Entrepreneurship, 16*(2).

Janošik, M., Vukotić, S., & Milenkovski, L. (2024). ANALYSIS OF POSSIBLE IMPACT FACTORS ON THE DEVELOPMENT OF THE ENTREPRENEURIAL INITIATIVE. *Ekonomika*, *70*(1).

Jiao, H., Wang, T., Libaers, D., Yang, J., & Hu, L. (2025). The relationship between digital technologies and innovation: A review, critique, and research agenda. *Journal of Innovation & Knowledge, 10*(1), 100638.

Juergensen, J. J., Love, J. H., Surdu, I., & Narula, R. (2024). Learning-by-exporting: The strategic role of organizational innovation. *International Business Review, 33*(6), 102339.

Khefacha, I., Romdhane, R., & Haj Salem, H. (2024). Unveiling the relationship between entrepreneurial aspirations and prosperity: An international panel study using GEM data. *International Entrepreneurship and Management Journal, 20*(1), 421-449.

Lin, Y. H., Lu, L. H., & Tang, S. Y. (2023). Entrepreneurial orientation and product innovativeness: the mediating roles of technology diversity and intellectual property protection. *Technology Analysis & Strategic Management*, 1-14.

Love, J. H., & Ganotakis, P. (2013). Learning by exporting: Lessons from high-technology SMEs. *International business review, 22*(1), 1-17.

Love, J. H., & Roper, S. (2015). SME innovation, exporting and growth: A review of existing evidence. *International small business journal, 33*(1), 28-48.

Ma, C. A., Xiao, R., Chang, H. Y., & Song, G. R. (2022). Founder management and innovation: An empirical analysis based on the theory of planned behavior and fuzzy-set qualitative comparative analysis. *Frontiers in psychology, 13*, 827448.

Matić, M., Leković, B., & Bobera, D. (2023). The influence of barriers on entrepreneurial intentions: Student entrepreneurship in Western Balkan countries. *Anali Ekonomskog fakulteta u Subotici, 59*(50), 51-66.

Matić, M., Leković, B., Marić, D., & Milutinović, S. (2025). THE INFLUENCE OF RELATIONS WITH CUSTOMERS ON PRODUCT INNOVATIONS ON THE TERRITORY OF AP VOJVODINA. *TEME*, 1033-1048.

Močnik, D., & Širec, K. (2016). Growth aspirations of early-stage entrepreneurs: Empirical investigation of South-Eastern and Western European countries. *Journal of East European Management Studies*, 298-317.

Munyo, I., & Veiga, L. (2024). Entrepreneurship and economic growth. *Journal of the Knowledge Economy, 15*(1), 319-336.

Nambisan, S. (2017). Digital entrepreneurship: Toward a digital technology perspective of entrepreneurship. *Entrepreneurship theory and practice, 41*(6), 1029-1055.

Ognjenović, K. (2024). Examining entrepreneurial intentions through the lens of university students' attitudes. *Anali Ekonomskog fakulteta u Subotici, 60*(52), 003-019.

Omari, D., Serwaah, P., Adomako, S., & Amankwah-Amoah, J. (2025). R&D Support, Digital Entrepreneurship, and Product Innovation. *R&D Management*.

Poblete, C. (2018). Growth expectations through innovative entrepreneurship: The role of subjective values and duration of entrepreneurial experience. *International Journal of Entrepreneurial Behavior & Research, 24*(1), 191-213.

Poblete, C. (2022). The joint effects of hubris, growth aspirations, and entrepreneurial phases for innovative behavior. *Frontiers in Psychology, 13*, 831058.

Radaković, M. Z. (2024). Enterprises' effectiveness: A study on structure, focus and enterprises' outcomes. *Anali Ekonomskog fakulteta u Subotici, 60*(52), 039-057.

Ramos-Hidalgo, E., Edeh, J. N., & Acedo, F. J. (2022). Innovation adaptation and post-entry growth in international new ventures. *European Research on Management and Business Economics, 28*(1), 100169.

Stojanović, M., Miljković, I. B., Obradović, J., & Dimitrijević, L. (2023). The impact of imports and exports on economic growth: Panel data analysis. *EKOHOM KA*, 69.

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THE NATURE OF CURRENCY CRISES: GLOBAL LESSONS AND FORECASTING SYSTEMS

Abstract

This paper seeks to present the essence and models for predicting currency crises based on the theoretical background and evidence of currency crises in the world. Extensive literature has been used to delve deeper into the mechanisms of action of currency crises on representative examples of countries. The findings suggest that there are different causes of currency crises, but that there are certain typical patterns of movement of certain macroeconomic indicators that are predictors of currency crises. The study, based on a systematic review of empirical experiences, emphasizes that the root causes lie in the poor economic fundamentals on which the economy rests: high inflation, unfavourable economic structure, fiscal deficit, speculative attacks on the currency and political instability. Such findings can contribute to monetary authorities and researchers in building models for the early detection of currency crises based on these variables. In addition, it was concluded that without international aid, countries were not able to quickly cope with the currency crisis.

Key words: *currency crises, financial crises, exchange rates, early warning systems for crisis, monetary policy*

JEL classification: *F30, F47, G01, G17, G28*

ПРИРОДА ВАЛУТНИХ КРИЗА: ГЛОБАЛНЕ ПОУКЕ И СИСТЕМИ ЗА ПРЕДВИЂАЊЕ

Апстракт

Овај рад настоји да прикаже суштину и моделе за предвиђање валутних криза на основу теоријске позадине и евиденције валутних криза у свету. Опсежна литература је коришћена како би се дубље зашло у механизме деловања валутних криза на репрезентативним примерима земаља. Налази говоре да постоје различити узроци валутних криза, али да ипак постоје одређени типични обрасци кретања одређених макроекономских показатеља који представљају предикторе валутних криза. Студија, на

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основу систематског прегледа емпиријских искустава, наглашава да основни узроци леже у лошим економским фундаментима на којима привреда почива: висока инфлација, неповољна привредна структура, фискални дефицит, шпекулативни напади на валуту и политичка нестабилност. Оваква сазнања могу допринети монетарним властима и истраживачима у изградњи модела за рано откривање валутних криза заснованих на овим варијаблама. Додатно, закључено је да без међународне помоћи земље нису успевале брзо да се изборе против валутне кризе.

Кључне речи: *валутне кризе, финансијске кризе, девизни курсеви, системи раног упозоравања на кризу, монетарна политика*

Introduction

Financial crises have plagued the world, especially since the last century. Sometimes the causative agents are from the real sector, and sometimes it can be banking crises. Moreover, in some cases, it is impossible to find a clear cause of a crisis, because it is a set of circumstances that influence the occurrence and development of financial crises. Panic in the market without a clear cause (spread of rumours, for example) can also be a trigger for the emergence of a banking crisis and then a financial crisis. Financial crises are often facilitated by factors from the country, and in a globalized world there is a growing insight into the effect of external factors that do not leave any country protected: whether it is a small, medium, large country, or even regardless of the level of financial and economic development. That is why this research is useful to a wide audience that includes economic and public policy makers, states, researchers, and the entire academic community. All countries can draw lessons, because all of them, we emphasize again, are a possible "target" of crisis strikes. Over the past 100 years, the world has faced several devastating crises that have shaken the global economy and financial markets. The Great Depression (1929-1933), the oil shock (1973 oil crisis) and the global financial crisis (2007-2009) left a significant mark on all of humanity. These major crises seem to have occurred, as a rule, about 40 years apart. The COVID-19 crisis has also left its mark on the conduct of international business and has threatened the functioning of the global economy, finance, and trade (Stojadinović-Jovanović, Krstić, Marković, 2020). We do not want to be pessimistic, but following previous patterns of manifestation, we can say that in the future the question is not whether the crisis will occur, but only when it will manifest its (often devastating) effect.

While some researchers deal with the origins and determinants of currency crises in a theoretical sense, others aim to predict future crises using various techniques and tools. This study aims to find the most common empirical factors that can be a threat to currency resilience, as well as to propose systems for evaluating and monitoring currency crises. The factors are complex because it is a multidimensional crisis. Moreover, it is often not possible to say what the root cause of the crisis is, because it can be caused by an entire range of factors that can be from the interior, but also from abroad. This study looks at the determinants of the crisis based on numerous examples of currency crises

in earlier decades: the crisis of the European Currency Mechanism, the currency crises in Mexico, Asia, Russia, Brazil, Argentina, Türkiye, Venezuela. Some countries are still dealing with the consequences of the same, while in Russia and Argentina, for example, currency crises had multiple episodes. The experience of the analysed countries shows that the following triggers of currency vulnerability were the most present: inflationary disturbances, speculative attacks on the currency, ineffective macroeconomic policy, poor choice of exchange rate regime, high private and public debt, the spread of crises (contagion) from abroad, budget problems, political turmoil, poor structure of the economy. These are the common causes of most of the currency crises that are evaluated in the paper. Although there is no precise classification of factors, in the literature it is possible to show factors that are classified according to currency crisis models, which will be further presented in the study. Also, the generations (models) of currency crises differ according to the dominant factors, although the fact is that a significant number of identical factors are present in each of the generations of currency crises.

On the other hand, the study offers a methodological framework that can be used for quick and early identification of currency crises. The authors offer a comprehensive insight into fractal analysis, a signal approach in identifying currency crises, as well as discrete choice models in their assessment. The paper also highlights the importance of certain modern techniques for considering the probability of currency crises, such as Markov models, artificial neural networks, and decision trees. The development of prediction systems based on machine learning will be the backbone of some scientists in the future to be prompt and better assessing the potential risks of financial crises of any type.

Insight into the causes of currency crises

Currency crises are a type of financial crisis. Financial crises arise as a disturbance resulting from the interactions of the financial and real sectors in an economy. They are most often explained as a sharp and rapid decline in the nominal value of a financial asset. If a crisis is caused in one of the major economies of the world, it leads to spread to other countries, which requires global coordination of the economic policies of the countries (Dabrowski, 2010). There is an entire range of factors that describe a financial crisis: rising interest rates, a strong depreciation of the national currency, mass panic and withdrawal of deposits, and a crisis of public debt and money circulation (Radelet, & Sachs, 2007). Hardy & Sever (2020) classify the determinants of currency crises into supply-side (decline in labour productivity, poor allocation of capital, and reduced investment in intangible capital), and demand-side (decline in consumption, demographic changes). Other authors point out the distinction between the factors of currency crises (as the key causes of financial crises) depending on whether the triggers are from home or abroad (Marjanović, & Marković, 2019a). Hindmoor & McConnell (2013) emphasize the signs of financial crises viewed more through the prism of banking crises: an unexpected rise in interest rates, an enormous increase in the number of non-performing loans, bankruptcies of large banks, a decrease in the amount of borrowed funds.

In many cases, financial crises are manifested by currency crises. The causes of currency crises can be different. The hasty liberalization of capital movements (credit

and financial sector), in the conditions of an inadequate regulatory framework (a system of supervision and control over banks as leading financial institutions) and the well-known effect of short-term speculative capital, has been identified in most studies as a trigger or reinforcing factor of currency crises (Marković, 2015). Throughout the scientific literature, a long list of factors of currency crises has been observed that are more likely to cause a real currency crisis if the central bank does not have optimal levels of foreign exchange reserves (Marjanović, & Marković, 2019). Among them are the drastic depreciation of the exchange rate, as well as the effect of hot money, which depletes the foreign exchange reserves managed by the central monetary institution. That is why the following terms are mentioned as synonyms for currency crisis in the literature: devaluation crisis, speculative crisis and foreign exchange crisis (Helísek, 2019).

A country with a currency crisis usually has a high depreciation of the national currency (over 25% annually) or the rate of currency depreciation (again on an annual basis) is 10 percentage points higher in the current year compared to the rate of depreciation in the previous year (Frankel, & Rose, 1996). In this case, monetary authorities usually sell foreign exchange reserves or raise interest rates to avoid speculative attacks. Therefore, Ari & Cergibozan (2016) emphasize that a currency crisis cannot be judged solely based on exchange rate movements; an indicator of a currency crisis can also be a drastic depletion of foreign exchange reserves. If a country chooses a bad (unsustainable) exchange rate regime, it is certain that at some point it will encounter the devastating effects of the currency crisis (Đolić, Marković, & Stojadinović-Jovanović, 2024). That is why monetary policy is a segment of economic policy that is crucial in preventing financial and currency crises (Anđelković, Kostić, & Milačić, 2025).

The factors of currency crises are often viewed in the literature through the study of the generation of currency crises. Based on practical experience, there are three generation models of currency crises that are presented with their root causes in Table 1.

Table 1. Models (generations) of currency crises and their determinants

The first generation of currency crises	The second generation of currency crises	The third generation of currency crises
- Mismanagement of monetary policy - A huge trade balance deficit - A high budget deficit - Excessive growth of domestic credit supply	- Speculative attacks on currency (hot money) - Bank panic and massive withdrawal of deposits - Pessimistic forecasts of investors	- Banking crisis - Over-indebtedness of the country - The high level of private sector debt - Moral hazard and negative selection - Accelerated liberalization of capital movements - Contagion from other countries

Source: Marković, & Marjanović, 2021

In contemporary professional and scientific circles, the need to develop a fourth-generation model of currency crises is discussed, bearing in mind some anomalies of existing models (Padhan, & Prabheesh, 2019). New comprehensive models can help to better understand and diagnose currency crises, better predict the vulnerability of

countries, but also offer more adequate argumentation of previous models to successfully implement anti-crisis policies.

Contemporary currency crises: records from the analysed countries

For many years, from 1979 to 1992, the global monetary system was extremely stable. However, starting in 1992, the unstable monetary situation in many countries has awakened the attention of theorists and practitioners in the field of economics to a phenomenon of a multidimensional nature, such as the currency crisis. The eroded stability of the European Monetary Mechanism was the initial source of growing concerns at the regional and global levels. This crisis was the result of post-German political conflicts that surfaced after reunification (Gordon, 2000), as well as misguided economic policy measures that caused high inflation and budget deficits in Italy and the United Kingdom (Higgins, 1993). Of course, speculative attacks were also an indispensable part of the process due to the pessimistic expectations of market participants, which was expressed especially after the referendum in Denmark (Rose, & Svensson, 1994). Further, the crisis spread to the Scandinavian countries and many currencies were devalued despite interventions through foreign exchange reserves. Finally, there was an adjustment of key interest rates, as well as the abandonment of currency pegs to the Deutsche Mark.

The devaluation of the peso at the end of 1994 triggered one of the biggest currency crises in recent history. It is about the currency crisis in Mexico, which is a mirror of the crisis of the first generation. Excessive budget spending and the consequent foreign debts have put the country in a difficult position. This was followed by political instability, a decrease in capital inflows, as well as a drastic decline in the amount of foreign exchange reserves. The failure of the devaluation has undermined the credibility of economic policymakers (Babić, & Žigman, 2000). This crisis threatened to take on global proportions, and in the end, the International Monetary Fund intervened with a sum of money that was intended to help vulnerable economies.

Asian countries (Singapore, Malaysia, Hong Kong, South Korea, Thailand, Taiwan) faced serious problems at the end of the last decade of the twentieth century, after a period of intense economic growth and development and overall socio-economic success (1965-1996). For many economists, the crisis was unexpected, while the monetary authorities were unprepared for the coming crisis. A huge amount of loans with low interest rates have become non-performing due to the depreciation of national currencies (Hughes, 2000). The inadequate debt structure in favour of the short-term one, as well as the too rapid removal of restrictions on the capital movement, has made many countries vulnerable. The high amounts of savings that were easily placed on the private sector were one of the reasons for the banking crisis. These are the classic consequences of the overheating of these economies, with loose regulation and supervision of financial institutions. The recovery of Asian countries did not come until 1999, after a serious restructuring of the banking sector, the establishment of better financial controls, and the reduction of foreign borrowing (Kawai, 1998).

Russia has been hit by a currency crisis since 1997. Pinto & Ulatov (2010) cite the reasons for the outbreak: (i) non-compliance with the agreed objectives of the fiscal

deficit reduction program, (ii) high political risk, and (iii) the monopsony power of certain banks. The fall in the prices of natural resources on which Russian exports are based, the low inflow of investments, as well as speculative attacks directly affected the occurrence of the currency crisis. The economy has not yet fully recovered, and the next crisis broke out shortly after, in 2014. Hidden problems gradually accumulated. It was obvious that at the same time Russia had certain unresolved problems in the structure of the economy, a sharp drop in the prices of oil and non-ferrous metals as the main export product, but this country also experienced economic sanctions from the United States and European countries, which were reflected to some extent in the weakening of macroeconomic parameters (Eberhardt, & Menkiszak, 2015).

Brazil was also a victim of the currency crisis in 1999. High inflation rates, as well as increased imports due to the overvaluation of the domestic currency, were the internal initiators of the crisis. Of the external factors, there was the effect of financial contagion from Russia and Asian countries (Marković, & Marjanović, 2021).

Argentina's economy, unlike before the crisis when it experienced an economic boom thanks to successful economic policies, has been very unstable since the beginning of the 21st century. The strengthening of the national currency, the illiquidity of companies and the "bank run" have accelerated the currency crisis (James, & Kulkarni, 2009). The crisis was contained thanks to international financial intervention. However, in 2018, Argentina experienced a new currency crisis, which again went through the consequences of this type of financial crisis. Of the obvious determinants, the huge budget deficit, natural disasters, but also the beginning of the pandemic in 2020 were in the lead. All this has led to the manifestation of high inflation, the depreciation of the currency, as well as the depletion of foreign exchange reserves.

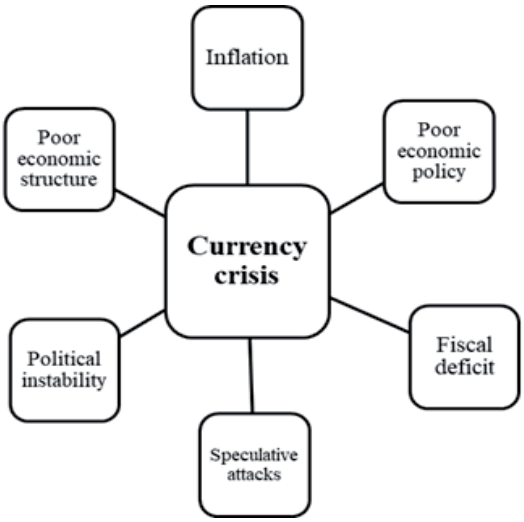
Egypt's currency crisis began in 2007 when the economy was hit by falling food and energy prices, which are crucial for this country (Boshkov, 2019). This crisis occurred at an inopportune time, just before the onset of the great global economic and financial crisis (2007-2008), which was particularly worrying and put the country's monetary and economic authorities in an uncomfortable position. International financial assistance was crucial for the country to recover by 2017 and to compensate for capital outflows due to a decline in foreign direct investment and foreign exchange inflows from tourism.

Similar common determinants of currency crises have been manifested in Türkiye. The currency crisis had the characteristics of a debt crisis. The balance of payments deficit, delays in measures and reforms of economic policies and high inflation rates have led the country to face one of the biggest crises in modern history (Öniş, & Kutlay, 2021). While the Turkish lira has stabilized with interest rate cuts and an adequate repayment plan, the pandemic has once again exposed the hidden weakness of the Turkish economy and the instability of the national currency (Orhangazi, & Yeldan, 2021).

Poor macroeconomic performance since 2012 has been the main cause of the crisis in Venezuela. More specifically, highly concentrated exports, growth in public spending, and rising borrowing costs, coupled with a decline in gross domestic product, have set the stage for a flare-up of the currency and economic crisis. The crisis was also contributed to by the so-called Dutch disease, a phenomenon related to over-reliance and favouritism on one product – oil in this case. A rather undiversified export, as well as the so-called rentier economy, makes a country very vulnerable if there is a fall in the price of the product in question on the global market (Buxton, 2021), which was the case in

Venezuela. Based on the previous evidence on the factors of currency crises, Figure 1 is constructed.

Figure 1. Common factors of the world's leading currency crises



Source: Authors' overview

Overview of early warning systems for currency crises

Currency crises are undesirable because they have a negative impact on all segments of the economy. They lead to a decline in economic activity, financial instability, and undermining the credibility of monetary and public authorities, causing the outflow of capital from the country and reducing investment. That is why systems and models are being developed to predict potential currency crises. Although they are imperfect, in fact, they are not able to completely stop the occurrence of crises with their predictive properties, the study and upgrade of these models is necessary to better assess future currency crises. Furthermore, failure to detect currency crises can be justified by a country's unstable macroeconomic fundamentals (Yépez, Flood, & Marion, 2010).

Early warning systems for currency crises combine economic and financial indicators to identify a country's vulnerability and/or the sustainability of the current exchange rate regime (Rădoi, & Gurau, 2019). Their power is to prevent economic losses associated with the outbreak of a crisis at an early stage, by allowing policymakers to assess the chances of its occurrence and respond on time. To begin with, it is necessary to distinguish between external and internal predictors of currency crises. The most important external indicators are exchange rate, foreign exchange reserves, current account of the balance of payments, and external debt, while the most common internal indicators are interest rate and non-performing loans (Abubakar, Utari, & Azwar, 2020). Irrational expectations of investors must also be considered, which can lead to the appearance of the so-called herd behaviour.

One of the techniques in the development of a system for assessing and predicting currency crises is a fractal analysis. It is based on the theory of fractals, which according to this system represent time series. In fact, it is a mathematical technique for studying the complex nature of financial indicators (Evertsz, 1995). Financial markets are non-linear, complex systems that are determined by a range of unknown parameters that are often beyond the control of market participants. There are many papers that prove the possible use of this analysis in forecasting financial crises (Sornette, & Zhou, 2004; Czarnecki, Grech, & Pamuła, 2008; Budinski-Petković et al., 2014).

Non-parametric models for assessing currency crises are most often related to the signal approach. This crisis detection system uses indicators that do not have a characteristic movement in the pre-crisis period. A signal for a potential currency crisis exists when the movement of a particular indicator deviates from a threshold value (Marković, & Marjanović, 2021). This signal warns that a currency crisis could occur in the next 24 months. Different authors use different indicators to predict future currency crises. One of the most cited papers that applies a signal approach to warn of possible episodes of currency crises uses the following parameters (Kaminsky, Lizondo, & Reinhart, 1998): banking crisis, international reserves, exports, imports, terms of trade, real exchange rate, the ratio of real interest rates on deposits in the country to real interest rates abroad (real interest differential), surplus money supply M1, M2 multiplier, value of domestic credits to the gross domestic product of the country, real interest rate on deposits, the relationship between lending rate and deposit rate, the value of deposits of commercial banks, the money supply of M3 relative to international reserves, the industrial output index and the stock price index. After defining the variables, this approach involves the following steps:

Step 1. Evaluation of indicators using the following matrix form (Berg, & Pattillo, 1999):

Table 2. Signal approach - matrix

	Crisis within 24 months	No crisis within 24 months
Signal was issued	A	B
No signal was issued	C	D

Source: Berg, & Pattillo, 1999.

where:

A – the number of months in which the indicator gave a good signal,

B – the number of months in which the indicator gave a bad signal,

C – the number of months in which the indicator did not issue a signal that should be a good signal,

D – the number of months in which the indicator did not issue a signal, which would be a bad signal.

Step 2. Defining the optimal threshold that minimizes the ratio of noise to signal (noise-to-signal ratio):

$$\frac{\frac{B}{B+D}}{\frac{A}{A+C}}$$

This step is very important because it selects a threshold value to achieve a balance between the risk of bad signals, on the one hand, and the risk that the signal does not occur, and that a currency crisis occurs, on the other.

Step 3. Calculation of the composite crisis indicator (Kaminsky, 1998):

$$k_t = \sum S_t^i * w^i$$

where:

k_t - composite indicator of the currency crisis.

S_t^i - this indicator is equal to one (1) if the indicator *i* exceeds the limit value, otherwise it is equal to zero (0),

w^i - the inverse ratio of the noise and signal of the indicator *i*.

Step 4. Calculating the conditional probability of a crisis by looking at how often a given index value is followed by a crisis over a 24-month period (Berg, & Pattillo, 1999):

$$\Pr\left(C_{t,t+24}^n | k_t = j\right) = \frac{months\ with\ k = j\ and\ a\ crisis\ within\ 24\ months}{months\ with\ k = j}$$

Here we obtain the value of the conditional probability of a currency crisis for the country *i* in the time interval [t, t+24].

Parametric models for predicting currency crises include discrete choice models and modern approaches that are still under development. First, discrete choice models (probit and logit models) are based on a binary variable: 1 – when a crisis is present, 0 – when there is no period with a crisis (Marjanović, & Marković, 2019a), with the aim of accurately detecting the occurrence of a currency crisis. Unlike the signal approach, this model determines the contribution of each of the indicators to the outbreak of the crisis. Demirgüç-Kunt & Detragiache (2005) support discrete choice models and criticize the signal approach because such an approach does not properly assess the potential for a crisis outbreak because it does not consider how far the value of a particular indicator is from a predefined threshold.

On the other hand, modern techniques for assessing currency crises are being developed to compensate for the perceived shortcomings of earlier models. They are primarily based on machine learning techniques but also include Markov models. A Markov model seeks to address some of the shortcomings of applying the discrete choice model in the construction of an early warning system for a crisis. A particular advantage lies in the fact that these models also incorporate some immeasurable factors, such as investor expectations, which are often subject to change (Fratzscher, 2002). Machine learning techniques usually involve the use of neural networks and decision trees. Artificial neural networks have emerged as a normal consequence of the following circumstances: (i) the development of modern science and technology, including the Big data, (ii) the need to reduce costs and, at the same time, increase the power of prediction (Nag, & Mitra, 1999), (iii) the need for more flexible models for forecasting currency crises (Fioramanti, 2008). The last technique within the framework of the currency crisis early warning system is the decision tree. It is an instrument that is based on the principles of classification and forecasting. It presents a kind of map of possible outcomes

of a series of choices that are interconnected. In crisis early warning systems, each node within the decision tree (binary trees) has two branches that symbolize outcomes. Then, the probability for each of the outcomes is determined, while the end node depicts the outcome of the decision trajectory.

Conclusion

Currency crises are one of the basic forms of financial crises that are unavoidable when there are economic and financial disturbances in domestic and global markets. Currency crises, sovereign debt crises, and banking crises are the most common examples of financial crises. In addition, scientists are also considering a twofold crisis. It is a combination of the currency crisis and banking crisis. The depreciation of the exchange rate and the drastic drop in foreign exchange reserves reflect the emergence and presence of a currency crisis in the country. The liberalization of capital flows, speculative attacks on the currency, as well as the so-called hot money (short-term capital that often moves from country to country) can be emphasized as the most common complementary factors of currency collapses. Additionally, currency vulnerability is more often manifested in small open countries that: poorly conduct economic policy, have a shallow financial market and are politically unstable.

Therefore, currency crises are obviously a negative phenomenon and have a harmful impact on the socio-economic development of the country, as well as on sustainable development. To build resilient societies, the potential problems that currency crises bring with them must be looked at in detail to construct an adequate regulatory framework. This research aims to attract attention to all stakeholders involved in the implementation of monetary, fiscal, and economic policy. Currency crisis detection systems must provide a timely alarm so that monetary authorities can react appropriately to prevent a possible currency crisis. The central bank has a dominant place in identifying, analysing, and taking preventive measures to counteract currency crises. However, the government institutions that manage fiscal policy are also making efforts to ensure coordination with monetary policy. The central bank has several instruments and measures whose prompt and effective use can help the country avoid the severe consequences of such crises. Since the trigger of currency crises can be the real or private sector, it is necessary to cooperate with the holders of all public policies and segments of economic policy. At the international level, the International Monetary Fund plays an important preventive role, both through financial resources and advisory services. Although there are divided opinions about the effectiveness of these measures, in the last resort, the role of this global institution in tackling currency crises can be crucial because modern financial systems are highly interconnected and often exposed to global events (shocks) at the same time. It is noted that the largest number of currency crises occurred in the last decade of the last century. After several years of stagnation, the 2007 crisis restarted the debate on the prevention of currency crises in many countries. Hence, there is a constant interest in scientific and academic circles in the study of nature, essence, and systems for assessing currency crises based on experience from the world.

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References

Abubakar, A., Utari, G. D., & Azwar, P. (2020). Early Warning Indicators and Optimal Policies for Mitigating Economic Crises: Evidence from Meta-Analysis. *Buletin Ekonomi Moneter Dan Perbankan*, 23(2), 269–294. https://doi.org/10.21098/bemp.v23i1.1421

Anđelković, T., Kostić, V., & Milačić, L. (2025). Impact of the American banking crisis on European banks. *Ekonomika*, 71(1), 69–81. https://doi.org/10.5937/ekonomika2501069A

Ari, A., & Cergibozan, R. (2016). A Comparison of Currency Crisis Dating Methods: Turkey 1990-2014. *Montenegrin Journal of Economics*, 12(3), 19–37. https://doi.org/10.14254/1800-5845.2016/12-3/3

Babić, A., & Žigman, A. (2000). *Валутне кризе: прегледи теорије и искуства 1990-тих*. Хрватска народна банка.

Berg, A., & Pattillo, C. (1999). Predicting currency crises: The indicators approach and an alternative. *Journal of international Money and Finance*, 18(4), 561–586. https://doi.org/10.1016/S0261-5606(99)00024-8

Boshkov, T. (2019). EGYPT CURRENCY CRISIS: ANALYSIS OF THE CAUSES. *International Journal of Information, Business and Management*, 11(1).

Budinski-Petković, L., Lončarević, I., Jakšić, Z. M., & Vrhovac, S. B. (2014). Fractal properties of financial markets. *Physica A: Statistical Mechanics and its Applications*, 410, 43–53. https://doi.org/10.1016/j.physa.2014.05.017

Buxton, J. (2021). Continuity and change in Venezuela's Bolivarian Revolution. In *Revolutions* (pp. 111-127). Routledge.

Czarnecki, Ł., Grech, D., & Pamuła, G. (2008). Comparison study of global and local approaches describing critical phenomena on the Polish stock exchange market. *Physica A: Statistical Mechanics and its Applications*, 387(27), 6801–6811. https://doi.org/10.1016/j.physa.2008.08.019

Dabrowski, M. (2010). The global financial crisis: Lessons for European integration. *Economic systems*, 34(1), 38–54. https://doi.org/10.1016/j.ecosys.2010.01.002

Demirgüç-Kunt, A., & Detragiache, E. (2005). Cross-country empirical studies of systemic bank distress: a survey. *National Institute Economic Review*, 192(1), 68–83. https://doi.org/10.1177/002795010519200108

Đolić, A., Marković, M., Stojadinović-Jovanović, S. (2024). Accumulation of Foreign Exchange Reserves in the Function of Preventing Currency Crisis. *Economics of Sustainable Development/ Економика одрживог развоја*, 8(1), 41–49. https://doi.org/10.5937/ESD2401041D

Eberhardt, A., & Menkiszak, M. (2015). The economic and financial crisis in Russia–background, symptoms and prospects for the future. *OSW Report 02/2015*.

Evertsz, C. J. (1995). Fractal geometry of financial time series. *Fractals*, 3(03), 609–616.

Fioramanti, M. (2008). Predicting sovereign debt crises using artificial neural networks: a comparative approach. *Journal of Financial Stability*, 4(2), 149–164. https://doi.org/10.1016/j.jfs.2008.01.001

Frankel, J. A., & Rose, A. K. (1996). Currency crashes in emerging markets: An empirical treatment. *Journal of International Economics*, 41(3-4), 351–366. https://doi.org/10.1016/S0022-1996(96)01441-9

Fratzscher, M. (2002). Financial market integration in Europe: on the effects of EMU on stock markets. *International Journal of Finance & Economics*, 7(3), 165–193. https://doi.org/10.1002/ijfe.187

Gordon, R. J. (2000). The Aftermath of the 1992 ERM Breakup: Was There a Macroeconomic Free Lunch? (pp. 241–284). University of Chicago Press.

Hardy, B., & Sever, C. (2021). Financial crises and innovation. *European Economic Review*, 138, 103856. https://doi.org/10.1016/j.euroecorev.2021.103856

Helísek, M. (2019). Exchange Rate Mechanism II and the risk of currency crisis–empiricism and theory. *Journal of International Studies*, 12(1), 297–312. https://dx.doi.org/10.14254/2071-8330.2019/12-1/20

Higgins, B. (1993). Was the ERM crisis inevitable? *Economic Review Federal Reserve Bank of Kansas City*, 78, 27–27.

Hindmoor, A., & McConnell, A. (2013). Why didn't they see it coming? Warning signs, acceptable risks and the global financial crisis. *Political Studies*, 61(3), 543–560. https://doi.org/10.1111/j.1467-9248.2012.00986.x

Hughes, C. W. (2000). Japanese policy and the East Asian currency crisis: abject defeat or quiet victory? *Review of international political economy*, 7(2), 219–253. https://doi.org/10.1080/096922900346956

James, B., & Kulkarni, K. G. (2009). Critique and Analysis of the Currency Crisis in Argentina. *The Journal of Applied Business and Economics*, 9(3), 1.

Kaminsky, G. L. (1998). Currency and banking crises: A composite leading indicator. *International Finance Discussion Paper Series*, 629.

Kaminsky, G., Lizondo, S., & Reinhart, C. M. (1998). Leading indicators of crises. *Staff Papers*, 45(1), 1–48. https://doi.org/10.2307/3867328

Kawai, M. (1998). The East Asian currency crisis: causes and lessons. *Contemporary Economic Policy*, 16(2), 157–172. https://doi.org/10.1111/j.1465-7287.1998.tb00509.x

Marjanović, I., Marković, M. (2019). Causality between exchange rates and foreign exchange reserves: Serbian case. *Facta universitatis, Series: Economics and Organization*, 16(4), 443–459. https://doi.org/10.22190/FUEO1904443M

Marjanović, I., Marković, M. (2019a). Determinants of currency crises in the Republic of Serbia. *Zbornik radova Ekonomskog fakulteta u Rijeci: Časopis za ekonomsku teoriju i praksu/ Proceedings of Rijeka Faculty of Economics*. 37(1), 191–212. https://doi.org/10.18045/zbefri.2019.1.191

Marković, M., & Marjanović, I. (2021). *Одрживост режима девизног курса и валутне кризе у Републици Србији*. Ниш: Друштво економиста „Економика".

Marković, M. (2015). Domestic and external factors of currency crises. *Facta Universitatis, Series: Economics and Organization*, 12(2), 121–128.

Nag, A., & Mitra, A. (1999). Neural networks and early warning indicators of currency crisis. *Reserve Bank of India Occasional Papers*, 20(2), 183–222.

Öniş, Z., & Kutlay, M. (2021). The anatomy of Turkey's new heterodox crisis: the interplay of domestic politics and global dynamics. *Turkish Studies*, 22(4), 499–529. https://doi.org/10.1080/14683849.2020.1833723

Orhangazi, Ö., & Yeldan, A. E. (2021). The re-making of the Turkish crisis. *Development and change*, 52(3), 460–503. https://doi.org/10.1111/dech.12644

Padhan, R., & Prabheesh, K. P. (2019). Effectiveness of early warning models: A critical review and new agenda for future direction. *Buletin Ekonomi Moneter dan Perbankan*, 22(4), 457–484. https://doi.org/10.21098/bemp.v22i4.1188

Pinto, B., & Ulatov, S. (2010). *Financial globalization and the Russian crisis of 1998* (No. 5312). *Policy Research Working Paper*. The World Bank.

Radelet, S., & Sachs, J. (2007). *The Onset of the East Asian Financial Crisis* (pp. 105–162). University of Chicago Press.

Rădoi, M. A. & Gurau, M. (2019). Early Warning Systems for Currency Crises. *Global Economic Observer*, 7(2), 88–98.

Rose, A. K., & Svensson, L. E. (1994). European exchange rate credibility before the fall. *European Economic Review*, 38(6), 1185–1216. https://doi.org/10.1016/0014-2921(94)90067-1

Sornette, D., & Zhou, W. X. (2004). Evidence of fueling of the 2000 new economy bubble by foreign capital inflow: implications for the future of the US economy and its stock market. *Physica A: Statistical Mechanics and its Applications*, 332, 412–440. https://doi.org/10.1016/j.physa.2003.10.010

Stojadinović Jovanović, S., Krstić, B., Marković, M. (2020). International business and management in pandemic-related conditions. *Economics of Sustainable Development*, 4(2), 25–36. https://doi.org/10.5937/ESD2002025S

Yépez, J. F., Flood, R. P. & Marion, N. P. (2010). A Perspective on Predicting Currency Crises. *IMF Working Paper* No. 10/227.

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COMPARATIVE ANALYSIS OF CIRCULAR ECONOMY PERFORMANCE: EVIDENCE FROM EUROPE

Abstract

The transition towards the circular economy (CE) model has gained recognition as a critical component in envisioning a sustainable future for humanity, owing to the inherent unsustainability of the current linear economic model of production and consumption. By repurposing resources and goods at the end of their useful lives, CE seeks to minimize waste creation while extending the life of these materials and products in the manufacturing cycle. The European Commission (EC) has backed switching from linear to CE to decrease undesirable interactions between the economy and the environment. Performance indicators developed under the CE monitoring framework are the best instruments for monitoring progress towards CE. The purpose of the current research is to examine the CE performance of the European Union (EU) countries – the Netherlands, France, and Germany. The analysis demonstrates strong relationships between important environmental parameters and the way they affect CE performance through a neural network procedure. The insights gained from this study, along with the broader research context provided by related studies, enhance the understanding of the difficulties and complexities in implementing and monitoring CE progress in different contexts.

Key words: *circular economy, performance indicators, comparative analysis, neural networks, EU countries*

JEL classification: *Q51, Q56, Q57*

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КОМПАРАТИВНА АНАЛИЗА ПЕРФОРМАНСИ ЦИРКУЛАРНЕ ЕКОНОМИЈЕ: ЕМПИРИЈСКА АНАЛИЗА НА ПРИМЕРУ ЕВРОПЕ

Апстракт

Транзиција ка моделу циркуларне економије (ЦЕ) препозната је као кључна компонента у обликовању одрживе будућности човечанства, с обзиром на инхерентну неодрживост тренутног линеарног економског модела производње и потрошње. Циркуларна економија настоји да минимизира стварање отпада кроз поновну употребу ресурса и производа на крају њиховог животног циклуса, продужавајући тако век трајања материјала и производа у производном процесу. Европска комисија (ЕК) подржала је прелазак са линеарног на циркуларни модел како би се смањиле негативне интеракције између економије и животне средине. Индикатори перформанси садржани у Оквиру за мониторинг ЦЕ представљају најбоље инструменте за праћење напретка ка циркуларној економији. Циљ овог истраживања је испитивање перформанси ЦЕ у земљама Европске уније (ЕУ) – Холандији, Француској и Немачкој. Анализа показује снажну повезаност између кључних еколошких параметара и њиховог утицаја на перформансе ЦЕ путем поступка неуронске мреже. Увиди стечени овим истраживањем, заједно са ширим истраживачким контекстом сродних студија, доприносе бољем разумевању изазова и сложености у имплементацији и праћењу напретка ЦЕ у различитим контекстима.

Кључне речи: циркуларна економија, индикатори перформанси, компаративна анализа, неуронске мреже, земље ЕУ

Introduction

With the focus on recycling, reusing, and cutting waste in order to create a more sustainable future, CE has become an important strategy for the advancement of sustainability. Ezeudu et al. (2022) state that CE encourages social justice, economic prosperity, and environmental quality – the fundamental principles of sustainable development. This concept advocates for a transformation from the traditional linear model of 'take-make-dispose' to a more sustainable, closed-loop system where resource use is optimized, and waste is minimized (Marković et al., 2020; Rađenović & Živković, 2023; Radivojević et al., 2024). Currently, just 7.2% of the world economy is circular, and this percentage is falling yearly as a result of rising material extraction and consumption (Circle Economy, 2024). Due to fast industrialization and population growth, there is an alarming trend in the rising exploitation and use of resources worldwide. Hence, a change in society's attitudes from materialism to more environmentally friendly production and consumption practices is needed.

Fostering CE and combining technology into various industrial strategies and regulations to ensure competitive, sustainable, low-carbon, and resource-efficient economies has particularly been the focus of the EU (Korhonen et al., 2018). In 2015, EC adopted the "Closing the Loop - An EU Action Plan for the Circular Economy"

announcing the transition to a CE as a strategic move towards sustainability. The Action Plan envisaged CE to offer significant benefits to EU countries, including improved competitiveness by safeguarding businesses from resource scarcity and volatile prices, creating new business opportunities, introducing innovative production and consumption methods, and creating local jobs across various skill levels (EC, 2015). Additionally, CE contributes to energy saving, biodiversity preservation, and pollution reduction, aligning with key EU priorities like job growth, climate and energy, social agenda, and industrial innovation (EC, 2015). The EU's role is recognized as pivotal in enabling this transition through regulatory frameworks, investment stimulation, and other supportive mechanisms. Accordingly, to evaluate the success of initiatives aimed at promoting the CE in the EU, the "Measuring Progress Towards Circular Economy in the European Union - Key Indicators for a Monitoring Framework" was adopted in 2018 (EC, 2018). This was followed by the adoption of "A new Circular Economy Action Plan For a cleaner and more competitive Europe", which projected that implementing CE principles throughout the EU economy could boost GDP by an additional 0.5% by 2030 and generate about 700.000 new jobs (EC, 2020). Further, the plan aims to accelerate the transformational change required by the European Green Deal to reach climate neutrality by 2050 (European Council, 2023), while decoupling economic growth from resource use and building on CE actions implemented since 2015 (EC, 2020). Finally, the plan emphasizes EU-level action with added value, calling for long-term engagement from Member States, regions, and global cooperation, aligning with the United Nations "The 2030 Agenda for Sustainable Development" (UN, 2015) and achieving sustainable development goals (SDGs), particularly Goal 12 on ensuring sustainable consumption and production patterns.

However, the implementation and progress in adopting CE models vary significantly across regions, necessitating a comparative analysis to understand these disparities better. The relevance of CE is particularly pronounced in the EU countries, given their diverse economic landscapes and environmental challenges. Thus, the current research aims to provide a comparative analysis of CE indicators across EU nations, namely the Netherlands, France, and Germany. It focuses on evaluating and critically analysing the adoption and effectiveness of CE practices across these countries by employing a neural networks approach. Through this analysis, the paper will contribute to the understanding of the dynamics and complexities involved in transitioning to a CE, offering insights into the successes and challenges faced by selected EU countries. The findings will not only aid in policy formulation but also provide a framework for other regions looking to implement or enhance their CE strategies.

The manuscript is structured in the following way. Firstly, the introduction is followed by a section covering the theoretical background and literature review on CE performance indicators. Then, the data and methods section come next. Finally, the report concludes with a discussion of the research findings and their implications on CE performance in the selected EU countries using Neural Designer-Machine Learning Software.

Theoretical backgrounds and Literature review

Resource extraction, production, transportation, and storage activities in the conventional linear economy model are major contributors to greenhouse gas emissions

(Smol et al., 2020). However, switching to a CE can help reduce emissions, mainly from resource exploitation and production processes. By adopting strategies such as waste reduction, energy-efficient production, and using renewable resources, carbon footprint can be reduced and climate resilience enhanced (Yang et al., 2023). Additionally, through particular strategies like recycling, re-manufacturing, and reuse, a CE helps mitigate resource scarcity, ensuring that valuable materials are kept in productive use for longer periods, thereby reducing the need for extraction of virgin resources (Payet, 2021). CE fosters innovation and economic growth by creating new business opportunities, stimulating investment in sustainable technologies, and driving efficiency gains across value chains. By redesigning products and processes to minimize waste and maximize resource use, diverse economic entities can unlock cost savings, enhance competitiveness, and tap into emerging markets for green products and services (Caldera et al., 2022). Furthermore, the change to a CE facilitates research and development in fields such as sustainable transportation, renewable energy, and eco-materials science, among others, spurring technological innovation (Jinqiao et al., 2022; Anttonen et al., 2018). With no less importance is the fact that CE promotes different kinds of economic and social resilience by diversifying supply sources, reducing dependability on virgin resources, and creating closed-loop systems that minimize supply chain vulnerabilities. By localizing production, adopting modular designs, and implementing reverse logistics, businesses can enhance their resilience to external shocks and uncertainties, ensuring continuity of operations and supply (Islam et al., 2022). Moreover, by prioritizing sustainable practices and resource-friendly considerations, a CE promotes fair labour practices, human rights, and social justice, contributing to a more equitable and inclusive society. The process of transition to a CE is vital and essentially sustainable observed from a global perspective if it addresses pressing challenges such as resource scarcity, climate change, environmental pollution, economic growth, natural hazards resilience, etc.

Recent studies have underscored the importance of developing and analysing CE indicators to gauge the progress of different regions towards SDGs. For instance, Geng et al. (2012) emphasized the role of national CE indicators, particularly in the context of China, highlighting their importance in policy-making and achieving CE outcomes. The knowledge gained from Chinese efforts on CE indicators, emphasizing the need for a comprehensive set of sustainability indicators including social and business indicators, is valuable to both developed and developing countries seeking to implement CE principles within their regulatory policies.

Similarly, Korhonen et al. (2018) critically examined the concept of CE and its limitations, emphasizing the need for scientific rigor in defining and operationalizing CE indicators. According to Gregson et al. (2015), EU policies often overlook global recycling networks, focusing instead on transforming waste into resources within the EU, which poses challenges to CE effectiveness. CE has limited enactment in the EU due to political and moral concerns. Mhatre et al. (2021) argue that infrastructure, laws, and technology availability contribute to the CE in the EU, with recycling being the most popular option. Mazur-Wierzbicka (2021) points to the fact that different countries within the EU have adopted varying strategies, as well as the variations in the extent to which these have been effective in meeting the challenges of a CE.

Silvestri et al. (2020) explore the adoption of the CE at the regional level within the EU, by developing the CE Static Index (CESI) and the CE Dynamic Index (CEDI),

which permitted both a static and a dynamic evaluation of the CE performance of EU regions. Garcia-Bernabeu et al. (2020) created a composite indicator called CE, using TOPSIS approach and a unique aggregation methodology, to evaluate EU nations' performance and highlight areas for improvement. They highlighted the need for a comprehensive monitoring framework at the national level to aggregate various CE dimensions. The study by Robaina et al. (2020) revealed that the efficiency of resource productivity and the determinants for a CE in Europe vary widely. They highlighted that there are noticeable differences in CE advancement between European countries, influenced by different policies and socio-economic development levels.

Vranjanac et al. (2023) used SmartPLS to study how CE innovation affects performance in EU nations. They found that supportive environments and financing are crucial for innovation to boost performance. The authors discussed the necessity of investments in research and innovations to improve recycling efficiency and support the secondary raw materials market. The findings contribute to understanding the dynamics of CE innovations and their effects on performance within the EU context. Radivojević et al. (2024) investigated the relationship between CE practices and economic growth by analysing data from 27 EU countries over 2000-2021. They specifically examined the impact of three CE indicators – Resource Productivity (RP), Generation of municipal waste per capita (MWpc), and Recycling rate of municipal waste (RRMW) – on GDP per capita. The findings revealed that CE practices not only enhance environmental sustainability but also significantly contribute to economic growth in EU countries. This reinforces the need for integrated policies to promote CE principles as part of sustainable development strategies.

However, notwithstanding the increasing volume of scholarly work on CE, there is a gap in comparative studies specifically focusing on the selected EU countries – the Netherlands, France, and Germany. By adopting CE principles and practices, countries, regions and inter-countries entities can unlock environmental, economic, and social benefits, securing a more sustainable and resilient future for generations to come. The selection of France, Germany, and the Netherlands for the research tasks in this study was influenced by their pioneering efforts in networking and collaborating with the Indo-Pacific region. The Indo-Pacific region has gained widespread acknowledgement as the preeminent geo-economic and geostrategic focal point globally. In economic terms, these nations account for a large part of the world's population, GDP, and marine trade. They present a unique context due to their varied stages of economic development, regulatory environments, and cultural perspectives on sustainability.

Initially, France was the country that initiated the focus on this region, mostly because of its significant historical-colonial legacy. Following France, Germany, and the Netherlands have joined cooperation programs with the Indo-Pacific region, creating national guidelines. In the context of the EU as a supranational entity, despite the undeniable importance of the Indo-Pacific region, scholarly literature addressing the burgeoning interest of the EU in the region remains relatively sparse (Weiqing & Yang, 2024). Nonetheless, Europe possesses significant interests, broadly categorized into economic, environmental, and normative domains, as delineated in recent academic publications (Abbondanza & Wilkins, 2023). Economically, the Indo-Pacific stands as the second-largest export destination for the EU, with the combined trade between the EU and the Indo-Pacific constituting approximately 70% of global trade. Moreover, their economies frequently exhibit complementary attributes.

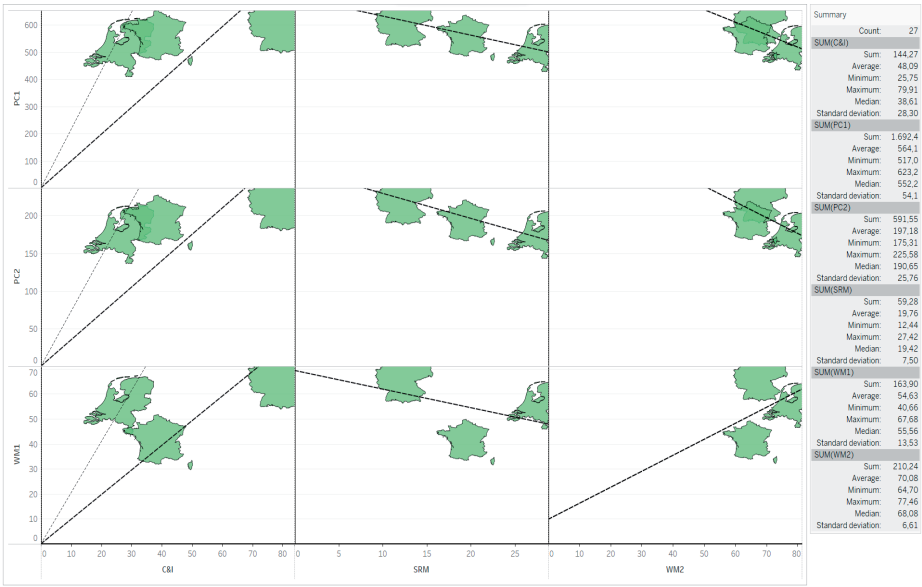
Having this in mind, the conclusions and Joint Communication on the EU Strategy for cooperation in the Indo-Pacific were adopted in 2021 (EC, 2021). Among other things, this Strategy focuses on the fulfilment of specific activities, such as: partnerships and cooperation agreements, value chains, trade negotiations, green alliances, ocean governance, research and innovation, connectivity partnerships, and others. The EU's engagement in the region includes initiatives to promote sustainable resource management practices, enhance environmental governance frameworks, and address transboundary environmental challenges through regional cooperation mechanisms. In the end, The EU's Indo-Pacific strategy includes initiatives to promote research collaboration, capacity-building, and knowledge exchange on environmental issues, leveraging scientific expertise and technological innovations to support SDGs achievements and environmental protection efforts. (EC, 2024).

This paper fills the gap by providing a comparative evaluation of CE indicators across these countries, drawing insights from the latest research and policy developments. This study analysis is grounded in the understanding that CE is not just an environmental or economic strategy, but a comprehensive approach that intersects with technological, cultural, and policy dimensions. As highlighted by Kirchherr et al. (2018), cultural and market barriers play a significant role in adopting CE practices across the EU, pointing to the complexity of implementing CE strategies. This paper, therefore, adopts a multi-dimensional approach to analyse the CE indicators, considering the interplay of these diverse factors through a neural network approach.

Methodology and Data

Following a neural network software solution, this research methodology examines three EU countries: the Netherlands, Germany, and France. The objective is to determine the relationship between inputs and outputs as a target variable in the context of a comparative study and a CE paradigm. Neural network applications have become more popular in the CE because of their functional features, reduced data needs, and ability to predict the future over the long term (Nema et al., 2017). There are several benefits over conventional analytical techniques. To construct the best neural network architecture for certain CE performance metrics, the Neural Designer-Machine Learning Software solution was applied. This is because it takes some intelligence to read the obtained data and analyse them effectively. This software offers applied comparative analysis that can predict trends, establish correlations, and identify patterns between inputs and outputs using a variety of effective neural network algorithms (Lopez, 2023). The approach involves starting with a small number of neurons and gradually increasing complexity until certain halting conditions are met. Additionally, this predictive model's expanding inputs approach is used in selecting inputs. By determining the correlation between each input and each output in the data set, this approach constructs a neural network that only includes the inputs that are most closely connected with the correct outputs (Hennemann Hilario da Silva & Sehnem, 2022). The neural network approach was used to evaluate which indication had the greatest influence and the most significant relationship between the input and output variables. Specifically, the study focuses on certain selected countries that have made progress in implementing the CE, particularly from an environmental point of view.

Figure 1: Descriptive statistics map chart with trend lines for average values of selected indicators 2016-2020



Source: Author's visualization according to available data from Eurostat Database

The most effective tools for monitoring progress toward the realization of CE principles are CE performance indicators. These indicators are part of the CE Monitoring Framework (Eurostat, 2023) and were chosen based on the most recent average values of the indicators for the countries selected from the Eurostat Database, for the five years 2016-2020 (Figure 1):

- Generation of municipal waste per capita (PC1) – indicator measures (Kg/capita) the waste collected by or on behalf of municipal authorities and disposed of through the waste management system. (Eurostat 2020a)
- Generation of packaging waste per capita (PC2) – indicator measures (Kg/capita) the packaging waste quantity in EU Member States. Packaging waste means any packaging or packaging material covered by the definition of waste in the Waste Framework Directive (EC, 2008), excluding production residues. (Eurostat 2020b)
- Recycling rate of municipal waste (WM1) – indicator measures (%) the share of recycled municipal waste in the total municipal waste generation. (Eurostat 2020c)
- Recycling rate of packaging waste by type of packaging (WM2) – indicator is defined as the share of recycled packaging waste in all generated packaging waste (%). (Eurostat 2020d)
- Circular material use rate (SRM) – the indicator calculates the percentage of material that is recycled and repurposed into the economy, hence reducing the amount of basic raw materials extracted during material consumption. The ratio of the circular material usage to the total material use is called the circularity

rate, or circular material use. More secondary resources replace primary raw materials, lowering the environmental effects of primary material extraction, is indicated by a greater circularity rate (%) value. (Eurostat 2020e)

- Patents related to waste management and recycling (C&I) – the patent indicator keeps a count of the number of patents related to secondary raw materials and recycling. This count is based on the Cooperative Patent Classification (CPC) codes used to attribute recyclables and secondary raw materials. However, it is important to note that this indicator only illuminates the latest recycling technology and does not cover all waste management technologies or other circular economy services and business models. (Eurostat 2020f).

Research results and Discussion

An analysis of the input variables' correlations was conducted using the Neural Designer software to identify the variables with the strongest correlation. Table 1 reveals that the generation of municipal trash per capita (PC1) and the generation of packaging waste per capita (PC2) have the highest correlation, with a coefficient value of 0.99 indicating their joint contribution to the output variable. Moreover, their positive correlation suggests that the three EU nations followed a similar approach in developing their output variable. On the other hand, the highest negative correlation, which is -0.99, has variables Generation of packaging waste per capita (PC2) and Circular material use rate (SRM), which means that these variables have a diametrically opposite effect on the output variable and are not dependent on each other.

Table 1 Correlation coefficient of the analysed CE indicators

Indicators	PC1	PC2	WM1	WM2	SRM	C&I
Generation of municipal waste per capita (PC1)*	1	0.99	0.61	-0.58	-0.99	0.98
Generation of packaging waste per capita (PC2)		1	0.63	-0.56	-0.99	0.99
Recycling rate of municipal waste (WM1)			1	0.39	-0.51	0.68
Recycling rate of packaging waste by type of packaging (WM2)				1	0.73	-0.58
Circular material use rate (SRM)					1	-0.99
Patents related to waste management and recycling (C&I)						1

*Note: PC1 indicator and PC2 indicator are inversed proportional

Source: Author's calculation

The chart below illustrates the impact of input variables on the output variable GERMANY, based on their respective values. A positive value for an input variable results in an increase in the output variable. Conversely, when an input variable is increased and the output variable is decreased, it produces a negative value. In case the output variable is close to zero, it indicates that changes in the input variable do not have any significant effect on it. Based on the Figure 2 below, the three most relevant inputs of this model are:

- PC1 with a value of -0.286.
- WM1 with a value of 0.232.
- PC2 with a value of -0.054.

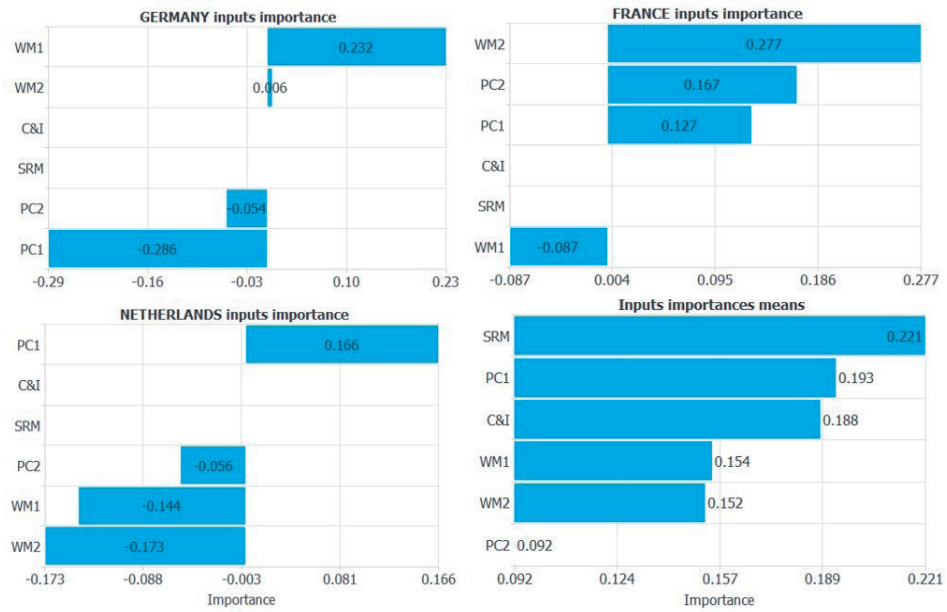
Germany has effectively increased its recycling rates over the past ten years, with almost two-thirds of its municipal solid waste (MSW) going through the processes of digestion, composting, and recycling. The recycling rate, inclusive of material recycling and composting/digestion, has maintained a consistent level of 67% over the past five years. France has witnessed a gradual rise in its recycling rate (Figure 2), climbing from 42.9% in 2016 to 45.1% in 2018, but experiencing a decline thereafter. By 2020, the recycling rate has reached 42.7%. Simultaneously, the proportion of waste sent to landfills has decreased, dropping from 22.4% in 2016 to 18.1% in 2020:

- WM2 with a value of 0.277.
- PC2 with a value of 0.167.
- PC1 with a value of 0.127.

Between 2016 and 2019, the Netherlands produced around 9 million tonnes of municipal garbage, a consistent level. But in 2020, the total climbed to 9.3 million tonnes, a 5.8% rise. According to Figure 2 the three most relevant inputs of this model are:

- WM2 with a value of -0.173.
- PC1 with a value of 0.166.
- WM1 with a value of -0.144.

Figure 2: Inputs importance across the countries and Overall importance 2016-2020



Source: Authors' elaboration from the Neural Designer

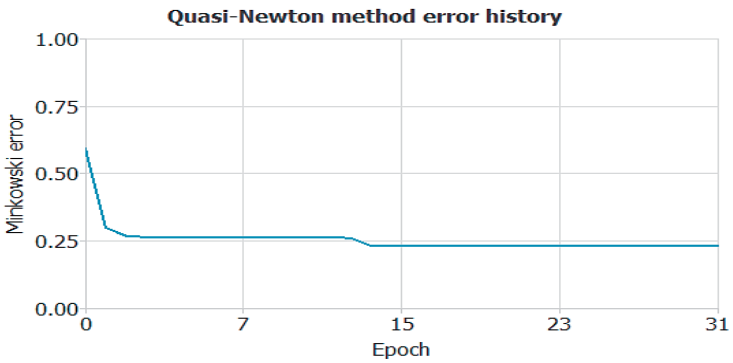
The selected EU countries exhibit substantial variations in SRMs, with percentages ranging from 27.5% in the Netherlands to 12% in Germany. France, during the analysed period, maintained a mean SRM of 19%. These disparities highlight notable distinctions in recycling capabilities and material consumption levels among analysed nations. In the

analysed context, Germany produced a considerable 620 kilograms of municipal waste per capita, surpassing the EU average of 527 kilograms (Perestrello, 2022). Meanwhile, the Netherlands consistently generated around 9 million tonnes of municipal waste between 2016 and 2019. However, in 2020, there was a notable 5.8% increase, resulting in a total of 9.3 million tonnes. On a per capita basis, the Netherlands averaged 517 kilograms of municipal waste. France is in the middle with an average poverty indicator of municipal waste generation per capita, with a mean value of 552 kg/capita. Based on the highest number of patents, Germany leads in waste management and recycling innovations with 80 patents. This positions it as the innovation leader among analysed countries, significantly surpassing others. Following closely are France with 39 patents and the Netherlands with 26 patents. It can be concluded OVERALL inputs importances means of this model are (Figure 2):

- SRM with a value of 0.221.
- PC1 with a value of 0.193.
- C&I with a value of 0.188.

The training strategy is the process that is used to train a neural network. During training, the neural network is taught to minimize loss by adjusting its parameters. The type of training provided is determined by how these parameters are adjusted. In this case, the quasi-Newton approach is used for training. Unlike Newton's approach, it does not require the computation of second derivatives. Instead, the quasi-Newton approach uses gradient information to approximate the inverse Hessian at each iteration of the algorithm (Song, 2018). The following chart shows how the error decreases with the epochs during the training process.

Figure 3: Quasi-Newton method of error history



Source: Authors' elaboration from the Neural Designer

This model's accuracy is based on the Minkowski error (R), where 2 is the reference value. In this model (Figure 3), the Minkowski error starts at 0.59 and decreases to 0.23 after 31 epochs, indicating that the model is accurate.

$$E = \frac{1}{R}\sum_{n}\sum_{k=1}^{c}|y_k(x_n;W) - t_{kn}|^R$$

where E is error function, R is number 2, y_k is the output layer, x_n is the input layer, W is weights array, t is time (Christiansen et al., 2014)

Another one model validity checker is the root mean square error, a statistic that indicates the average difference between the model's predicted values and the dataset's actual values, can be used to evaluate how well a neural network model fits a dataset. A model's ability to "fit" a dataset improves with a decreased root mean square error (RMSE). The root mean square error, or RMSE for brief, can be calculated using the following formula:

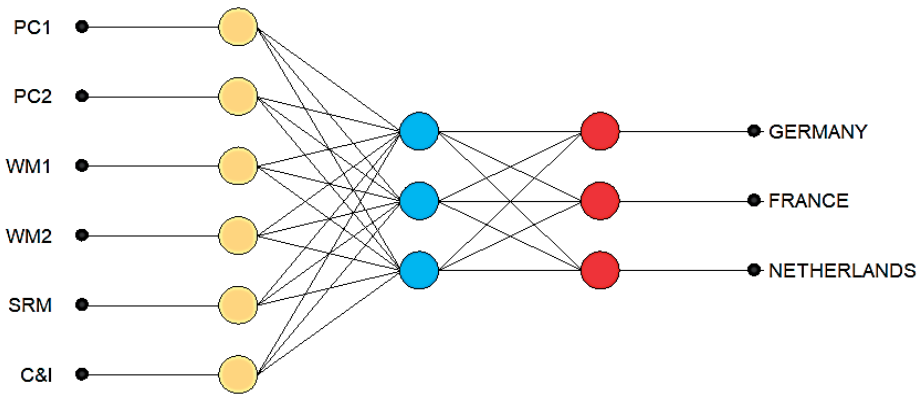
$$RMSE = \sqrt{\frac{\sum(P_i - O_i)^2}{n}}$$

where Σ is a fancy symbol that means "sum", P_i is the predicted value for the i^{th} observation in the dataset, O_i is the observed value for the i^{th} observation in the dataset and n is the sample size. RMSE value in this model is 0.68 which indicates the satisfactory validity (very-good (0-0.50), good (0.50-0.60), satisfactory (0.60-0.70), or unsatisfactory (>0.70)) following Moriasi et al. (2007).

Lastly, Figure 4 displays the graphical depiction of the deep architecture that was produced as a result of the in-depth comparison analysis of a few chosen circular economy indicators. A neural network, an unscaling layer, and a scaling layer are all present. Yellow circles stand for scaling neurons, blue circles for perceptron neurons, and red circles for unscaling neurons. For every six inputs, there are three outputs generated. The neural network architecture's three levels of complexity are indicated by the quantity of hidden neurons. The network architecture is shown graphically in the following diagram. It contains the subsequent layers:

- Scaling layer with 6 neurons (yellow).
- Perceptron layer with 3 neurons (blue).
- Probabilistic layer with 3 neurons (red).

Figure 4 Neural network architecture for the input/output comparative analysis of the selected EU countries



Source: Authors' calculation in the Neural Designer-Machine Learning Software

The following listing presents the mathematical equation represented by neural network Box 1. This equation generates the outputs GERMANY, FRANCE, and NETHERLANDS based on the inputs PC1, PC2, WM1, WM2, SRM, and C&I. In classification models, the neural network spreads information in a feed-forward manner across the scaling, perceptron, and probabilistic layers.

Box 1: Mathematical expression of the neural network comparative analysis

```
scaled_PC_one_ = (PC_one_-564.1329956)/38.25189972;
scaled_PC_two_ = (PC_two_-197.1820068)/18.2159996;
scaled_WM_one_ = (WM_one_-54.63330078)/9.569849968;
scaled_WM_two_ = (WM_two_-70.08000183)/4.674630165;
scaled_SRM = (SRM-19.76000023)/5.300320148;
scaled_C_amprsn_I = (C_amprsn_I-48.08929825)/20.00769997;

perceptron_layer_1_output_0 = tanh (-0.0260498 + (scaled_PC_one_*-0.150281) + (scaled_PC_two_*0.0269897) + (scaled_WM_one_*0.126636) + (scaled_WM_two_*0.108936) + (scaled_SRM*0.191541) + (scaled_C_amprsn_I*-0.164575));
perceptron_layer_1_output_1 = tanh (0.1125 + (scaled_PC_one_*0.184082) + (scaled_PC_two_*-0.129688) + (scaled_WM_one_*0.096521) + (scaled_WM_two_*-0.0174927) + (scaled_SRM*-0.0272949) + (scaled_C_amprsn_I*0.0316406));
perceptron_layer_1_output_2 = tanh (-0.0515625 + (scaled_PC_one_*-0.169043) + (scaled_PC_two_*-0.0744629) + (scaled_WM_one_*0.0323364) + (scaled_WM_two_*-0.196545) + (scaled_SRM*-0.173767) + (scaled_C_amprsn_I*-0.0827881));

probabilistic_layer_combinations_0 = 0.139343 +0.0166138*perceptron_layer_1_output_0 -0.0495239*perceptron_layer_1_output_1 -0.101257*perceptron_layer_1_output_2
probabilistic_layer_combinations_1 = -0.177722 -0.0802124*perceptron_layer_1_output_0 -0.0871948*perceptron_layer_1_output_1 -0.195862*perceptron_layer_1_output_2
probabilistic_layer_combinations_2 = 0.0154907 -0.197656*perceptron_layer_1_output_0 -0.059082*perceptron_layer_1_output_1 -0.123779*perceptron_layer_1_output_2
sum=exp(probabilistic_layer_combinations_0)+exp(probabilistic_layer_combinations_1) + exp(probabilistic_layer_combinations_2);

GERMANY = exp(probabilistic_layer_combinations_0)/sum;
FRANCE_ = exp(probabilistic_layer_combinations_1)/sum;
NETHERLANDS = exp(probabilistic_layer_combinations_2)/sum
```

Conclusion

The efficacy of the CE paradigm can be assessed through multiple functional lenses, including economic, social, and ecological dimensions. Its performance can be spatially evaluated across various territorial scales, ranging from regional to global levels, utilizing diverse modelling techniques ranging from rudimentary numerical methods to sophisticated artificial intelligence approaches such as neural networks. In that sense, this scientific paper uniquely contributes by examining the CE performance within the

context of three distinct EU countries, highlighting the novel selection of these entities for performed analysis.

Given the diverse economic landscapes and environmental challenges across EU countries, the CE is particularly relevant in the selected EU countries – the Netherlands, Germany, and France. The Netherlands was the third member of the EU to adopt an Indo-Pacific strategy, after Germany and France. To protect and advance Dutch political and economic interests, the Dutch government initiated an unambiguous choice in November 2020 towards a more active Dutch and EU posture in the Indo-Pacific. The German Policy guidelines for the Indo-Pacific are very extensive, begging the question of whose goals are to take precedence if difficult decisions need to be taken. The largest obstacle is allocating the required funds and personnel to meet the expectations that have been established among Indo-Pacific countries. Overall, the EU's efforts to optimize and adapt circular infrastructure are demonstrated by the umbrella strategy covering the entire EU.

Consequently, this study aims to add to the body of knowledge about evaluating CE performance in this area. Moreover, the study employs an advanced methodological framework incorporating optimized neural network architectures tailored to specific CE performance metrics. The study utilizes a neural network software solution to explore relationships between various input and output variables in CE performance across three Indo-Pacific EU countries. Six key indicators from the EU CE monitoring framework were analysed: Generation of municipal waste per capita, Generation of packaging waste per capita, Recycling rate of municipal waste, Recycling rate of packaging waste by type, Circular material use rate, and Patents related to waste management and recycling. The applied optimization process uses a mathematical model to find the ideal operating conditions in comparing the above-mentioned EU countries. This predictive model enables authors to reproduce various operating scenarios and modify control variables to increase efficiency. Particularly, performance circularity optimization means finding the rules that, by the CE concepts, minimize or maximize the performance variables for a specific set of countries participating in the Indo-Pacific Agreement.

A notable finding from this analysis is the strong correlation between the generation of municipal waste per capita and the generation of packaging waste per capita, highlighting the joint contribution of these input variables in the formation of output variables in CE. The importance of input variables on the output variable for Germany, as an example, demonstrates the influence of these indicators on national CE performance. By accelerating the procedures for product sorting and breakdowns, component refurbishment, and material recycling, machine learning can assist in the development and enhancement of the reverse logistics infrastructure needed to "close the loop" on goods and materials. To support efforts to fundamentally reshape the economy into one that is resilient, regenerative, and long-term fit, integrating the power of machine learning with a vision for a CE represents a significant, and currently unexplored opportunity to harness one of the outstanding technological developments of stakeholders' energy.

While acknowledging the imperfections of the model, it signifies a significant advancement in the analytical capabilities concerning CE performance within the selected entities. Furthermore, the model's adaptable architecture offers flexibility, enabling modification of existing CE performance indicators and integration of new ones. Future research endeavours should focus on refining composite indicator structures, expanding

the scope of input variables, and devising additional relevant metrics, such as the virtual material use rate, to further enhance analytical depth and accuracy.

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References

Abbondanza G., Wilkins T., (2023). Europe in the Indo-Pacific: Economic, security, and normative engagement. *International Political Science Review*. https://doi.org/10.1177/01925121231202694

Anttonen M., Lammi M., Mykkänen J., Repo P., (2018). Circular economy in the triple helix of innovation systems. *Sustainability.* https://doi.org/10.3390/su10082646

Caldera S., Jayasinghe R., Desha C., Dawes L., Ferguson S., (2022). Evaluating Barriers, Enablers and Opportunities for Closing the Loop through 'Waste Upcycling': A Systematic Literature Review. *Journal of Sustainable Development of Energy, Water and Environment Systems,* 10(1):1–20. https://doi.org/10.13044/j.sdewes.d8.0367

Christiansen N.H., Voi P., Winther O., Høgsberg J., (2014). Comparison of Neural Network Error Measures for Simulation of Slender Marine Structures. *Journal of Applied Mathematics*, 1-11. https://doi.org/10.1155/2014/759834

Circle Economy, (2024). *The circularity gap report 2024, https://www.circularity-gap.world/2024#download*, (30.01.2024).

EC, (2008). *Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives (text with EEA relevance). https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32008L0098.* (10.01.2024).

EC, (2015). *Closing the Loop - an EU Action Plan for the Circular Economy. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52015DC0614* (20.12.2023).

EC, (2018). *Measuring Progress Towards Circular Economy in the European Union – Key Indicators for a Monitoring Framework. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=SWD%3A2018%3A17%3AFIN* (20.12.2023).

EC, (2020). *A new Circular Economy Action Plan For a cleaner and more competitive Europe. https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1583933814386&uri=COM:2020:98:FIN* (20.12.2023).

EC, (2021). *The EU strategy for cooperation in the Indo-Pacific. https://www.eeas.europa.eu/eeas/joint-communication-indo-pacific_en.* (20.12.2023).

EC, (2024). *EU Indo-Pacific Strategy. https://www.eeas.europa.eu/sites/default/files/documents/2024/EU%20Indo-pacific%20FS-01-24-V3.pdf.* (10.01.2024).

European Council, (2023). *European Green Deal, https://www.consilium.europa.eu/en/policies/green-deal/* (10.01.2024).

Eurostat, (2020a). *Generation of municipal waste per capita (cei_pc031). https://ec.europa.eu/eurostat/cache/metadata/en/cei_pc031_esmsip2.htm*. (20.12.2023).

Eurostat, (2020b). *Generation of packaging waste per capita (cei_pc040) https://ec.europa.eu/eurostat/cache/metadata/en/cei_pc040_esmsip2.htm*. (20.12.2023).

Eurostat, (2020c). *Recycling rate of municipal waste (cei_wm011). https://ec.europa.eu/eurostat/cache/metadata/en/cei_wm011_esmsip2.htm* (20.12.2023).

Eurostat, (2020d). *Recycling rate of packaging waste by type of packaging (cei_wm020). https://ec.europa.eu/eurostat/cache/metadata/en/cei_wm020_esmsip2.htm* (20.12.2023).

Eurostat, (2020e). *Circular material use rate (cei_srm030) https://ec.europa.eu/eurostat/cache/metadata/en/cei_srm030_esmsip2.htm.* (20.12.2023).

Eurostat, (2020f). *Patents related to waste management and recycling (cei_cie020) https://ec.europa.eu/eurostat/cache/metadata/en/cei_cie020_esmsip2.htm* (20.12.2023).

Eurostat, (2023). *Circular economy monitoring framework. https://ec.europa.eu/eurostat/web/circular-economy/monitoring-framework.* (20.12.2023).

Ezeudu O.B., Agunwamba J.C., Ugochukwu U.C., Oraelosi T.C., (2022). Circular economy and frugal innovation: a conceptual nexus. *Environmental Science and Pollution Research* 29:29719–29734. https://doi.org/10.1007/s11356-022-18522-6

Garcia-Bernabeu A., Hilario-Caballero A., Plà-Santamaria D., Salas-Molina F., (2020). A Process Oriented MCDM Approach to Construct a Circular Economy Composite Index. *Sustainability.* https://doi.org/10.3390/su12020618

Geng Y., Fu J., Sarkis J., Xue B., (2012). Towards a national circular economy indicator system in China: an evaluation and critical analysis. *Journal of Cleaner Production* 23(1):216–224. https://doi.org/10.1016/j.jclepro.2011.07.005

Gregson N., Crang M., Fuller S., Holmes H., (2015). Interrogating the circular economy: the moral economy of resource recovery in the EU. *Economy and Society*, 44:218–243. https://doi.org/10.1080/03085147.2015.1013353

Hennemann Hilario da Silva T., Sehnem S., (2022). The circular economy and Industry 4.0: synergies and challenges, *Revista de Gestão*, 29(3):300–313. https://doi.org/10.1108/REGE-07-2021-0121

Islam M.T., Iyer-Raniga U., Trewick S., (2022). Recycling Perspectives of Circular Business Models: A Review. *Recycling,* 7, 79. https://doi.org/10.3390/recycling7050079

Jinqiao L., Maneengam A., Saleem F., Mukarram S.S., (2022). Investigating the role of financial development and technology innovation in climate change: evidence from emerging seven countries. *Economic research* 35(1):3940–3960. https://doi.org/10.1080/1331677X.2021.2007152

Kirchherr J., Piscicelli L., Bour R., Kostense-Smit E., Muller J., Huibrechtse-Truijens A., Hekkert M., (2018). Barriers to the circular economy: Evidence from the European Union (EU). *Ecological Economics* 150:264–272. https://doi.org/10.1016/J.ECOLECON.2018.04.028.

Korhonen J., Honkasalo A., Seppälä J., (2018). Circular Economy: The Concept and its Limitations. *Ecological Economics*, 143:37–46. https://doi.org/10.1016/J.ECOLECON.2017.06.041.

Lopez R., (2023). *What is Neural Designer? https://www.neuraldesigner.com/learning/user-guide/what-is-neural-designer/* (20.12.2023).

Marković M., Krstić B., Rađenović T., (2020). Circular economy and sustainable development. *Economics of sustainable development* 4(1):1–9. https://doi.org/10.5937/ESD2001001M

Mazur-Wierzbicka E., (2021). Circular economy: advancement of European Union countries. *Environmental Sciences Europe*, 33:1–15. https://doi.org/10.1186/s12302-021-00549-0

Mhatre P., Panchal R., Singh A., Bibyan S., (2021). A systematic literature review on the circular economy initiatives in the European Union. *Sustainable Production and Consumption*, 26. https://doi.org/10.1016/J.SPC.2020.09.008.

Moriasi D.N., Wilson B.N., Douglas-Mankin K.R., Arnold J.G., Gowda P.H., (2012). Hydrologic and Water Quality Models: Use, Calibration, and Validation. *Transactions of the ASABE*, 55:1241–1247. http://dx.doi.org/10.13031/2013.23153

Nema M.K., Khare D., Chandniha S.K., (2017). Application of artificial intelligence to estimate the reference evapotranspiration in sub-humid Doon valley. *Applied Water Science,* 7(7):3903–3910. doi: https://doi.org/10.1007/s13201-017- 0543-3

Payet J., (2021). Assessment of Carbon Footprint for the Textile Sector in France. *Sustainability,* 13, 2422. https://doi.org/10.3390/su13052422

Perestrello M., (2022). *Nato and the Indo-Pacific Region - Report https://www.nato-pa.int/document/2022-nato-and-indo-pacific-region-report-krimi-021-pcnp* (10.12.2023).

Radivojević, V., Rađenović, T., & Dimovski, J. (2024). The Role of Circular Economy in Driving Economic Growth: Evidence from EU Countries. *SAGE Open, 14*(4), 21582440241240624.

Rađenović T., Živković S., (2023). The Importance of Circular Economy for Sustainable Development. *Economic and Social Development: Book of Proceedings*, 186-198.

Robaina M., Villar J., Pereira E.T., (2020). The determinants for a circular economy in Europe. *Environmental Science and Pollution Research* 27:12566–12578. https://doi.org/10.1007/s11356-020-07847-9

Silvestri F., Spigarelli F., Tassinari M., (2020). Regional development of Circular Economy in the European Union: A multidimensional analysis. *Journal of Cleaner Production*, 255:120218–120260. https://doi.org/10.1016/j.jclepro.2020.120218

Smol M., Marcinek P., Duda J., Szołdrowska D., (2020). Importance of Sustainable Mineral Resource Management in Implementing the Circular Economy (CE) Model and the European Green Deal Strategy. *Resources.* 9(5):55. https://doi.org/10.3390/resources9050055

Song H., (2018). *Nature-Inspired VLSI Circuits - From Concept to Implementation*. Lulu.com, USA.

UN, (2015). *Transforming our World: The 2030 Agenda for Sustainable Development, https://sdgs.un.org/sites/default/files/publications/21252030%20Agenda%20for%20Sustainable%20Development%20web.pdf.* (10.01.2024).

Vranjanac Ž., Rađenović Ž., Rađenović T., Živković S., (2023). Modeling circular economy innovation and performance indicators in European Union countries. *Environmental Science and Pollution Research.* 30(34):81573–81584. https://doi.org/10.1007/s11356-023-26431-5

Weiqing S., Ziqing Y., (2024). Unpacking the EU's Indo-Pacific strategy: a testing case of strategic autonomy, *Australian Journal of International Affairs,* https://doi.org/10.1080/10357718.2024.2305650

Yang M., Chen L., Wang J., Msingwa G., Osman A., Fawzy S., Rooney D.W., Yap P.S., (2023). Circular economy strategies for combating climate change and other environmental issues. *Environmental Chemistry Letters* 21:55–80. https://doi.org/10.1007/s10311-022-01499-6

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TEMETTUAT DEFTER (PROFIT REGISTER) OF THE CHRISTIAN MAHALLES OF NIŠ (1845): POP STANKO'S MAHALLE[3]

Abstract

The paper presents a detailed translation of the temettuat defter of the Pop Stanko's mahalle in Niš (1845) and a comparative analysis of the income of its residents. Temettuat defters are a key primary source for researching the social and economic history of the regions under the Ottoman rule in the 19th century. What makes Pop Stanko's mahalle particularly interesting is the fact that it was the largest Christian community in Ottoman Niš in the 19th century, and after 1878 the largest Serbian settlement in this city (Palilula). Therefore, the aim of the research is to determine the economic profile of mahalle at the time when the aforementioned defter was made and thus to shed light on a phase in its evolutionary development, from a rural area on the outskirts of Niš into its urban city core such was Palilula.

Key words: *Niš, Palilula, Ottoman Empire, Christians, temettuat defter, 19th century*

JEL classification: *N33, N530, N930*

ТЕМЕТУАТ ДЕФТЕР (ДЕФТЕР ПРОФИТА) ХРИШЋАНСКИХ МАХАЛА У НИШУ (1845): ПОП СТАНКОВА МАХАЛА

Апстракт

Рад представља детаљан превод темеТуат дефтера Поп Станкове махале у Нишу (1845) и компаративну анализу прихода њених становника. ТемеТуат дефтери су кључан извор првог реда за истраживање социјалне и економске историје поднебља под османском управом у 19. веку. Оно што Поп Станкову махалу чини нарочито интересантном је чињеница да је у питању махала која је била највећа хришћанска заједница османског Ниша у 19. веку, а након 1878. године и највеће српско насеље у овом граду (Палилула). С тога, циљ истраживања је да се утврди привредни профил махале у време настанка реченог дефтера и на тај начин расветли једну фазу у њеном

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еволутивном развоју од руралне области на рубу Ниша у његово урбано језгро какво је била Палилула.

Кључне речи: *Ниш, Палилула, Османско царство, хришћани, темеtуат дефтер, 19. век*

Introduction

The Westernization of the Ottoman Empire, Tanzimat (1839–1876), is the era during which the Ottoman state attempted through a series of reforms to bridge the growing technological gap between itself and the leading countries of Christian Europe. Internally, this meant going through the necessary reorganization of state institutions, establishing the modern ones, and defining a clear and long-term course of internal progressive state policy. With this goal in mind, during a period spanning most of the 19th century, various modern schools were established throughout the Empire, new bureaucratic institutions and councils were introduced, almost every segment of industry was modernized, and the army was organized according to the European model.

The dynamics of these reforms were largely determined by the economic capacity of the Ottoman state. In the decades when the state was financially strong, sultans and progressive statesmen sovereignly implemented reforms in the spirit of the Tanzimat. However, when that was not the case, conservative and anti-reform circles grew stronger and threatened to jeopardize the progress. Therefore, the reformists during the Tanzimat were particularly focused on providing the state with stable economic resources for the sake of securing further development (Güran, 2014). One of the very first steps in this was to enumerate the income of the population, so that the state could pursue a flexible and reasonable tax policy. The achievements in that domain are decided to be evaluated through the newly introduced temettuat defters (profit registers).

Temettuat defters

The new tax policy was launched immediately after the promulgation of the Gülhane Hatt-ı Şerifi (1839), a document which announced the beginning of Tanzimat Era. According to the Hatt-ı Şerifi, all rights of non-Muslims and Muslims were equalized before the state, and everyone was guaranteed the security of property, regardless of religious or ethnic affiliation. All illegal taxes were abolished, as was the practice of leasing state taxes (iltizam). This prevented the private tax farmers, who leased the right from the state to collect the taxes, to multiply the tax collected and thus illegally exhaust the people. Therefore, in the future state taxes were collected only by the muhassıls, state officials who received a fixed salary for doing this job (İnalcık, 1978). Also, all taxes were unified under one state tax (Yükçü, 2017). According to the state's assessment, fair tax collection and the emancipation of non-Muslims should have led to greater accumulation of financial resources among them. It should directly affect the positive economic situation of areas where non-Muslims were the majority, mainly in

the European regions of the Ottoman empire (Rumelia). Therefore, the calculation of various profits (temettuat) accumulated by the population was a next logical move.

The temettuat defters provide systematized information about taxpayers, the real estate they own, animals, the amount of their income from commercial, craft and other activities, as well as the amount of taxes they have paid. The *taxes* is the crucial term here, so we will explain the novelties temettuat defters brought with this. As it was mentioned above, all taxes that taxpayers used to pay before 1839 were unified in Tanzimat. These taxes in the Classical period were labeled with the general name *tekâlif-i örfiye* and compiled a vast array of taxes. Depending whether tekâlif-i örfiye was farmed at rural estates (çiftliks) and villages in countryside or mahalles and kasabas in urban areas, this array could vary a bit. Now in Tanzimat the term *tekâlif-i örfiye* was changed into *vergi-i mahsusa*, or simply *vergi*, meaning a special tax or a tax on profit. Vergi was a collective tax which was determined to each sancak by the Ottoman Ministry of Finance. The sancak administration further distributed the payment of vergi according to the paying capacity of the kazas which were subordinate to it. In the kazas, local authorities further personalized the payment of vergi according to the paying power and share in the profit of the villages, mahalles, and çiftliks which made up the kaza. Since vergi was a collective tax, and the fixed rate threatened to burden the poor classes equally with the wealthy elite, at the lowest levels of tax collection care was taken to ensure that it was distributed according to the paying capacity of every taxpayer. In this way, every taxpayer got his economic profile.

Aside from vergi, temetuat defters also register the payment of tithes (aşar) on various products of the land that the taxpayer earned. Until the Tanzimat, aşar (i.e. öşür in the singular) was only nominally called tithe, while in practice it could tax up to 50% of crops that taxpayer grew on his land. Such a ratio was subjectively (and often biasedly) assessed by tax collectors and local officials, depending on how successful was the agricultural season or the fertility of the region. The Tanzimat put an end to this, so tithes were henceforth determined precisely, as a clear 1/10 of the land products that a taxpayer grew. Both vergi and aşar in temetuat defters were presented as taxes paid for the previous year, and at the end of the entry, the amount of general income the person earned was also stated, so that the future tax rate could be determined more precisely. The payment of the vergi and aşar, sometimes both and sometimes one of them, was made by exempt persons who did not make any profit, which was often evident from the fact that they did not have any real estate on their name. Clergymen, both Muslim and non-Muslim, were often exempt from taxes, too.

The Niš eyalet was included in both times (1840/41, 1844/45) when the temettuat defters were conducted as a pilot project. The idea of the state was to do the temettuat defters in the regions where the Tanzimat novelties had already been applied – Ankara, Aydın, Bolu, Cezâyir-i Bahr-i Sefîd, Edime, Erzurum, Bursa, Konya, Niš, Rumelia, Thessaloniki, Silistre, Sivas, Skoplje and Vidin (Yükçü, 2017).

Unfortunately, almost no temettuat defters from 1840/41 have survived today, and those from 1844/45 are divided into 9 catalogues, numbering 17 747 defters (Yükçü, 2017). Unlike the temettuat defters from 1840/41, when muhasills were the ones who gathered the data, the 1844/45 defters were conducted by the local notables responsible for the community which was covered by the defter. Among Muslims, these notables were the imams and mahalle representatives (muhtars) and among non-Muslims were

people like rabbis, priests, or village elders – köybaşıs (Kütükoğlu, 1995). After being confirmed with the seal of these enumerators, the temettuat defters were forwarded to the councils of kaza, and from there to the councils of higher administrative instance, sancak. From there they were checked by the financial manager (defterdar) and the governors of eyalet (vali), as higher authorities. In order to make the temettuat defter easier and more reliable to use in the practice, the defter sheets had a form with exemplary questions and answers, and then preliminary sent to the vali, defterdar and members of the responsible local councils so they could get familiar with the survey.

Although they are valid sources which provide a wide range of reliable data, from economic to demographic and religious, the temettuat defters are often plagued by shortcomings and inconsistencies on the part of the enumerators (which depended of their competence). That is why many temettuat defters lack data related to important categories, such as the vergi paid by a person, the amount of tithe collected, and even a sum of the collective income of whole mahalle, which, as a rule, should always be summarized at the end of the defter.

Temettuat defter of Pop Stanko's mahalle

Temettuat defter from 1844/45 followed the administrative organization of the Niš eyalet into 4 kazas (Niš, Prokuplje, Pirot and Samokov). Each of these kazas was further divided into villages and mahalles where the defter was conducted. Though in general the second time when the defter was done refers to the year 1261 by Hijri (1844/45), the date when defter in Niš was conducted is clearly stated. It was on 29 Zilhicce 1261 AH, meaning 29 December 1845, according to the Gregorian calendar. In the territory that encompasses the town of Niš, out of 21 mahalles we identified more than 10 non-Muslim mahalles and several çiftliks whose inhabitants were Christians, and which were related directly to Niš. Of those 10 Christian mahalles and *infidel* communities (neveryesi) in Niš 8 were named after the orthodox Christian priests, as Pop Kosta's, Pop Jova's, Pop Mita's, Pop Đorđe's, Pop Stanko's mahalle, plus Pop Naum's, Pop Jovan's and Pop Jovan's kefere neveryesi (Kordiç, 2019). Neveryesi might indicate Christian community settled in Muslim mahalle, which would make such mahalle a religiously heterogenous district. However, term *neveryesi* also might be a term for irregular Christian settlement, a slum town, in this case inhabited by the Christians on the outskirts of Niš. With 101 registered households, Pop Jovan's neveryesi was the biggest Christian community in Niš, however, with 83 households Pop Stanko's mahalle was the biggest fully recognized Christian district in administrative context. Although these two communities might be physically connected to each other, hence making a one body, we recognized Pop Stanko's mahalle as the core of district which will later grow into Palilula.

The anthroponymic findings clearly indicate that the residents of all these mahalles and çiftliks were predominantly Christian Serbs, which some names particularly point out (Ignjat, Goran-Goga etc.). However, Big and Small Gypsy mahalle (Kebir-i Kıbtiyan Mahallesi, Sağir-i Kıbtiyan Mahallesi) might be an exception, since their names indicate they were inhabited by Roma population. If that is the case, then Roma residents of those mahalles were of Orthodox Christian fate and already with the Slavic names. In general, most of the names are identified, but in some cases possible variations should be taken

in consideration, such as with the names Miladin/Mladen or Hrista/Krsta/Rista. Unique case was the name Lila, which is obviously a nickname or a shortened version of a name we could not reconstruct. Usually, we would consider it a misspelling of a scribe, but at the same time we found 2 more men with the name Lila in other mahalles in Niš. To add, a certain Lila (the son of Žika) with the rest of the Christian notables from Niš in 1858 signed a collective address to authorities about the installment of the new bishop of Niš (BOA, HR. SYS. 1772/1). So, we left the name Lila as it was written.

Regarding toponyms in the vicinity of Niš where certain people had land, in three cases we managed to identify villages as Malošište, Suvi Dol and Batušinac with relative certainty. But in other cases we had to keep the names as mere transliterations and mark them with an asterisk* (though some names were obviously of Slavic origin, but we could not locate and verify them as existing toponyms, such as Hrastinče, Izvor, Girašince).

The names of most of the professions have equivalents in English (kürkçü – furrier, ırgat – crop field worker/worker, bahçıvan – gardener, hizmetkar – household servant, meyhaneci – innkeeper etc.). However, some occupations are specific or were difficult to translate, so we have either clarified them with an endnote or kept them in the original. Kürekçi, for example, could mean a shovel-maker, but also a person who provides by working on a field with a shovel or a hoe, a crop field worker. The same goes for simitçi, who cannot be translated as a simple baker, but a person who bakes and sells a special kind of bagel, a simit. Kiracı is also a specific case. Though it could be understood as a profession (renter and rentier), in the context of temettuat defter it refers to a residential status of a person, therefore it should be understood as a newcomer, tenant (Todorov, 2024). Though kiracıs in general belong to a group of land cultivators, labeling them with this term adds particular value in researching demographic politics and migrations based on the temettuat defters.

We have also kept the monetary and measurement units in the original. When it comes to money, it is the silver kuruş (made of 40 paras, i.e. 120 akçes). The land is represented in dönüm (920 m^2), and the weight in kiye (~1.28 kg). We believe that by carefully and practically establishing these rules, we preserved the authenticity but also have overcome most of the problems which working with the Ottoman archival materials entails.

We have organized the data related to the Pop Stanko's mahalle in a composition which contains the following categories: the number of household in the mahalle, name of the taxpayer, his father's name (brackets with the letter f), the amount of the vergi for the previous year, the amount of crops in kiye that the taxpayer produced (and the tithe/aşar paid for it), the amount of the tax on alcohol (zecriye) for people who made brandies and wines from fruits they grew in their vineyards and orchards, agricultural holdings of the taxpayer – vineyards, meadows, pastures, fields (with income and paid tithe) and the name of the place where they are located (if the place is mentioned in the register), buildings/fields that the taxpayer has rented or leased (with the amount of kuruş earned or shared with other person), animals and livestock owned by the taxpayer, separate amounts of money taxpayer earned from his job and funds he received from property and other assets. In the Pop Stanko's mahalle, aside from the taxes already mentioned, the tax on sheep (adet-i agnam) is also documented, as another old tax imposed by the Ottomans, in addition to the tithe. Also, summary data on the vergi and the income of the all residents of mahalle (which should be at the end of the defter) are not shown.

The temettuat defter of this mahalle is combined with the defters of a few çiftliks which follow it and then the sum of all of them is stated together. This makes it difficult to draw a precise conclusion about the distribution of the vergi and other financial data related Pop Stanko's mahalle as community, so we stated nothing in this regard.

The temettuat defter which refers to Pop Stanko's mahalle is entitled as *Temettuat defter of reaya which live in Papaz Istanko mahalle*, and it goes like this:

Household no. 1. Carpenter Nikola (f. Stamen). Last year he paid vergi with 110 kuruş and aşar for 50 kiye of wheat (12 kuruş) and 50 kiye of corn (10 kuruş). He pays tax on alcohol (12 kuruş). He owns 2 dönüms of vineyards (income 165 kuruş per year) and 3 dönüms of land in Malošište (income 225 kuruş per year, taxed with 22 kuruş). His total income is 350 kuruş.

Household no. 2. Gardener Miša (f. Jovan). Last year he paid vergi with 95 kuruş in cash and aşar for 50 kiye of wheat (12 kuruş) and 20 kiye of corn (4 kuruş). He pays tax on alcohol (24 kuruş). He owns 3 dönüms of vineyards (income 300 kuruş per year), 1 dönüm of garden (income 50 kuruş per year) and 3 dönüms of land in Hrastinče* (income 165 kuruş). He keeps 1 mare and 1 female calf. He earns a total of 450 kuruş from gardening.

Household no. 3. Innkeeper Luka (f. Stojko). Last year he paid vergi with 95 kuruş and aşar for 200 kiye of wheat (50 kuruş) and 150 kiye of corn (20 kuruş). He owns 3 dönüms of vineyards (income 60 kuruş per year), 3 dönüms of meadows (income 60 kuruş per year), 15 dönüms of land (income 800 kuruş per year, taxed with 80 kuruş) in Batušinac. He keeps 1 cow. In total, he earns 780 kuruş from land and 550 kuruş from the tavern.

Household no. 4. Kiracı Miladin (f. Đorđe). Last year he paid vergi with 105 kuruş and aşar for 50 kiye of wheat (12 kuruş) and 100 kiye of corn (20 kuruş). He pays tax on alcohol (50 kuruş). He owns 5 dönüms of vineyards (income 450 kuruş per year) and 8 dönüms of land (income 325 kuruş, taxed with 32 kuruş) in Hrastinče. He keeps 1 donkey, 1 cow and a calf. In total, he earns 350 kuruş from work and 754 kuruş from other things.

Household no. 5. Tailor Pavle (f. Hrista). Last year he paid vergi with 69 kuruş and aşar for 100 kiye of corn (20 kuruş). He pays tax on alcohol (7 kuruş). He owns 2 dönüms of vineyards (income 75 kuruş per year) and 2 dönüms of land (income 180 kuruş, taxed with 20 kuruş) in Hrastinče*. In total, he earns 255 kuruş from land and 400 kuruş from work.

Household no. 6. Kumcu Stamen (f. Spasa). Last year he paid vergi with 160 kuruş and aşar for 200 kiye of wheat (50 kuruş) and 60 kiye of corn (12 kuruş). He pays tax on alcohol (23 kuruş). He owns 3 dönüms of vineyards (income 225 kuruş per year) and 2 parcels of 4 and 6 dönüms of land (income 320 kuruş, taxed with 62 kuruş). He keeps 1 mare. In total, he earns 782 kuruş from land and 500 kuruş from work.

Household no. 7. Innkeeper Filip (f. Goga). Last year he paid vergi with 180 kuruş and aşar for 100 kiye of wheat (25 kuruş), 200 kiye of barley (40 kuruş) and 140 kiye of corn (28 kuruş). He pays tax on alcohol (42 kuruş). He owns 4 dönüms of vineyards

(income 300 kuruş per year), 1 dönüm of garden (income 150 kuruş) and 4, 4 and 9 dönüms of land (income 930 kuruş, taxed with 93 kuruş) in Malošište, Isprazna* and Batušinac. He keeps 1 ox, 1 mare and 1 milking cow. In total, he earns 1250 kuruş from the tavern and 1339 kuruş from other things.

Household no. 8. Potter Miša (f. Rista). Vergi paid last year is not stated. He paid aşar for 100 kiye of wheat (25 kuruş) and 100 kiye of corn (20 kuruş). He pays tax on alcohol (9 kuruş). He owns 2 dönüms of vineyards (income 105 kuruş per year) and 8 dönüms of land (income 450 kuruş, taxed with 45 kuruş) in Malošište. He keeps 1 milking cow (income 12 kuruş). His total income is 350 kuruş from work and 522 kuruş from other things.

Household no. 9. Carpenter Bajča (f. Kole). Last year he paid vergi with 110 kuruş and aşar for 100 kiye of wheat (25 kuruş) and 40 kiye of barley (8 kuruş). He pays tax on alcohol (17 kuruş). He owns 2 dönüms of vineyards (income 255 kuruş per year) and 8 dönüms of land (income 330 kuruş, taxed with 33 kuruş) in Malošište. In total, he earns 350 kuruş from his craft and 553 kuruş from other things.

Household no. 10. Mutafçı Mita (f. Ćira). Last year he paid vergi with 38 kuruş. He earns in total 350 kuruş from his craft.

Household no. 11. Kiracı Živko (f. Krsta). Last year he paid vergi with 130 kuruş and aşar for 100 kiye of wheat (25 kuruş) and 50 kiye of corn (10 kuruş). He pays tax on alcohol (22 kuruş). He owns 3 dönüms of vineyards (income 90 kuruş per year) and 10 dönüms of land in Malošište (income 350 kuruş, taxed with 35 kuruş). He keeps 1 milking cow (income 12 kuruş) and 2 bulls. In total, he earns 350 kuruş from work and 417 kuruş from other things.

Household no. 12. Carpenter Rajko (f. Živko). Last year he paid vergi with 67 kuruş and aşar for (unspecified). He pays tax on alcohol (22 kuruş). He owns 3 dönüms of vineyards (income 150 kuruş per year). He keeps 1 milking cow (income 12 kuruş). In total, he earns 350 kuruş from work and 162 kuruş from other things.

Household no. 13. Household servant Paun (f. Goga). He pays tax on alcohol (21 kuruş). He owns 2 dönüms of vineyards (income 45 kuruş per year). He keeps 1 milking cow (income 12 kuruş). He earns a total of 150 kuruş from service and 57 kuruş from other things.

Household no. 14. Kiracı Paun (f. Stojan). Last year he paid vergi with 39 kuruş, and aşar for 100 kiye of wheat (25 kuruş). He pays tax on alcohol (10 kuruş and 20 para). He owns 2 dönüms of vineyards (income 150 kuruş per year) and 4 dönüms of land in Hrastinče* (income 250 kuruş, taxed with 25 kuruş). He keeps 1 bull. In total, he earns 350 kuruş from work and 375 kuruş from other things.

Household no. 15. A young man (sabi) Mika (f. Stanko). Last year he paid vergi (unspecified) aşar and for 100 kiye of wheat (25 kuruş). He pays tax on alcohol (10 kuruş). He owns 2 dönüms of vineyards (income 45 kuruş per year) and 4 dönüms of land in Malošište (income 250 kuruş, taxed with 25 kuruş). His total income is 382 kuruş.

Household no. 16. Kiracı Jovan (f. Cone). Last year he paid vergi with 95 kuruş and aşar for 100 kiye of wheat (25 kuruş). He pays tax on alcohol (57 kuruş). He rents

from Goga (f. Joka*) 5 dönüms of vineyards (income 225 kuruş per year) and 4 dönüms of land in Malošište (income 250 kuruş, taxed with 25 kuruş). He keeps 2 bulls and a milking cow (income 12 kuruş). In total, he earns 500 kuruş from work and 462 kuruş from other things.

Household no. 17. Cart driver Ignjat (f. Cvetko). Last year he paid vergi with 34 kuruş and aşar for 100 kiye of corn (20 kuruş). He pays tax on alcohol (10 kuruş and 30 para). He owns 2 dönüms of vineyards (income 120 kuruş per year) and 2 dönüms of land in Hrastinče (income 200 kuruş, taxed with 20 kuruş). He keeps a milking cow (income 12 kuruş) and 1 calf. In total, he earns 500 kuruş from work and 312 kuruş from other things.

Household no. 18. Saddle-maker Stojan (f. Apostol). Last year he paid vergi with 38 kuruş and aşar for 100 kiye of wheat (25 kuruş). He pays tax on alcohol (16 kuruş and 30 para). He owns 2 dönüms of vineyards (income 225 kuruş per year) and 2 parcels of 4 and 5 dönüms (income 330 kuruş, taxed with 33 kuruş) in Malošište and Isradan*. He keeps a pair of water buffalos and 1 milking buffalo (income 25 kuruş). In total, he earns 450 kuruş from work and 587 kuruş from other things.

Household no. 19. Kiracı Đorđe (f. unnamed). Last year he paid vergi with 160 kuruş and aşar for 200 kiye of wheat (50 kuruş), 50 kiye of barley (10 kuruş) and 100 kiye of corn (20 kuruş). He pays tax on alcohol (66 kuruş). He owns 6 dönüms of vineyards (income 750 kuruş per year), 2 dönüms of meadows (income 40 kuruş) and 2 parcels of land of 6 and 10 dönüms (income 800 kuruş, taxed with 80 kuruş) in Hrastinče* and Sudurun*. He keeps 4 bulls, one milking cow (income 12 kuruş), 2 breeding mares and 3 foals. In total, he earns 650 kuruş from work and 1482 kuruş from other things.

Household no. 20. Kiracı unnamed (f. Živko). Last year he paid vergi with 140 kuruş and aşar for 400 kiye of wheat (100 kuruş), 200 kiye of barley (40 kuruş) and 200 kiye of corn (40 kuruş). He pays tax on alcohol (17 kuruş). He owns 3 dönüms of vineyards (income 300 kuruş per year), 4 dönüms of meadows (income 80 kuruş) and 3 parcels of land of 5, 6 and 13 dönüms (income 1800 kuruş, taxed with 180 kuruş) in Hrastinče*, Kalna* and Sudurun*. He keeps 4 bulls, 2 milking cows (income 22 kuruş), 2 yearlings, 2 calves, 2 horses, 3 mares and 2 foals. He earns a total of 750 kuruş from business and 2022 kuruş from other income.

Household no. 21. Kiracı Petar (f. Cvetko). Last year he paid vergi with 110 kuruş and aşar for 100 kiye of wheat (25 kuruş) and 150 kiye of corn (30 kuruş). He pays tax on alcohol (12 kuruş). He owns 2 dönüms of vineyards (income 150 kuruş per year) and 2 parcels of land of 4 and 5 dönüms (income 550 kuruş, taxed with 55 kuruş) in Hrastinče* and Batušinac. He keeps 1 horse, a mare, a bull, a milking cow (12 kuruş of income) and 20 sheep (income 140 kuruş). He paid 2 kuruş of tax on sheep (adet-i agnam). In total, he earns 550 kuruş from business and 797 kuruş from other things.

Household no. 22. Crop field worker Bane (f. Petar). He owns only a house and earns 250 kuruş from work.

Household no. 23. Crop field worker Radonja (f. Spasa). He does not own any real estate. He keeps 1 horse and 1 calf of a black Anatolian cattle breed (karasıgır). He earns 250 kuruş in total.

Household no. 24. Rista (f. Milenko). No other data.

Household no. 25. Household servant Todor (f. Jovan). He did not pay taxes last year. He owns nothing and earns only from his service. Last year he earned 200 kuruş.

Household no. 26. Crop field worker Stamen (f. Sava). He did not pay taxes last year. He owns only a house and earns only from his service. Last year he earned 250 kuruş.

Household no. 27. Household servant Anta (f. Jova). He did not pay taxes last year. He owns only a house and earns only from his service. Last year he earned 120 kuruş.

Household no. 28. Simitçi apprentice Miladin (f. Petar). Last year he paid vergi with 29 kuruş. He owns only a house, and his income comes only from his job. Last year he earned 150 kuruş.

Household No. 29. Crop field worker Petar (f. Jovan). Last year he paid vergi with 30 kuruş. He owns only a house, and his income comes solely from his job. He owns 2 dönüms of vineyards (income of 90 kuruş per year). In total, he earns 250 kuruş from work and 90 kuruş from other things.

Household no. 30. Household servant Janko (f. Kole). He owns only a house, and his income comes solely from his service. Last year he earned 200 kuruş.

Household no. 31. Crop field worker Ranča (f. Đorđe). Last year he paid vergi with 15 kuruş. He pays tax on alcohol (23 kuruş). He owns 3 dönüms of vineyard (income 120 kuruş per year). In total, he earns 200 kuruş from his job and 120 kuruş from the vineyard.

Household no. 32. Carpenter Spasa (father'name not recorded). Last year he paid vergi with 90 kuruş and aşar for 100 kiye of wheat (25 kuruş) and 50 kiye of corn (10 kuruş). He owns 6 dönüms of land (income 350 kuruş, taxed with 35 kuruş) in Suvi dol. In total, he earns 315 kuruş from land and 400 kuruş from work.

Household no. 33. Crop field worker Milenko (f. Rista). He pays tax on alcohol (14 kuruş). He owns 2 dönüms of vineyards (income 105 kuruş per year). Total income 105 kuruş from vineyard and 350 kuruş from work.

Household no. 34. Crop field worker Đoka (f. Mita). He owns nothing. His total income is 105 kuruş from work.

Household no. 35. Furrier Zlatko (f. Anta). Last year he paid a vergi with 120 kuruş and aşar for 100 kiye of wheat (25 kuruş). He pays a tax on alcohol (80 kuruş). He owns 7 dönüms of vineyards (income 600 kuruş per year) and 3 dönüms of land (income 250 kuruş, taxed with 25 kuruş) in Girašince*. In total, he earns 825 kuruş from work and 600 kuruş from other things.

Household no. 36. Crop field worker Paun (f. Marko). He did not pay taxes last year. He pays tax on alcohol (10 kuruş). He owns 2 dönüms of vineyards (income 120 kuruş per year). He earns a total of 150 kuruş from work and 120 kuruş from the vineyards.

Household no. 37. Potter Todor (f. Manča). Last year he paid a vergi with 85 kuruş and aşar for 80 kiye of wheat (20 kuruş) and 50 kiye of corn (10 kuruş). He pays a tax on alcohol (48 kuruş). He owns 3 dönüms of vineyards (income 345 kuruş per year) and 5 dönüms of land (income 300 kuruş, taxed with of 30 kuruş) in Malošište. In total, he earns 550 kuruş from business and 615 kuruş from other things.

Household no. 38. Potter Du(š)an (f. Veljko). Last year he paid vergi with 68 kuruş. He pays tax on alcohol (15 kuruş). He owns a vineyard on 2 parcels of land of 2 and 3 dönüms (income 210 kuruş per year). He earns a total of 650 kuruş from his job and 90 kuruş from a lesser vineyard.

Household no. 39. Potter Stojan (f. Jovan). Last year he paid vergi with 85 kuruş and aşar for 100 kiye of wheat (25 kuruş) and 50 kiye of corn (10 kuruş). He pays a tax on alcohol (24 kuruş). He owns a vineyard of 3 dönüms (income of 225 kuruş per year) and 6 dönüms of land (income of 350 kuruş, taxed with 35 kuruş) in Suvi dol. He keeps 1 horse. He earns a total of 500 kuruş from job and 540 kuruş from other things.

Household no. 40. Household servant Andrija (f. Manča). Last year he paid vergi 10 kuruş. He owns nothing. His total income from a service is 150 kuruş.

Household no. 41. Crop field worker Ilija (f. Mita). The vergi he paid is not stated, but he paid aşar for 100 kiye of wheat (25 kuruş). He pays the tax on alcohol (11 kuruş). He owns 3 dönüms of vineyards (income 45 kuruş per year) and 1 dönüm of land (income 250 kuruş, taxed with 25 kuruş) in Malošište. He keeps a milking cow (income 12 kuruş) and a horse. His total income is 250 kuruş from work and 282 kuruş from other things.

Household no. 42. Innkeeper Petar (p. Ćira). Last year he paid vergi with 125 kuruş and aşar for 150 kiye of corn (20 kuruş). He pays a tax on alcohol (28 kuruş). He owns 3 dönüms of vineyards (income 120 kuruş per year) and 4 dönüms of land (income 300 kuruş, taxed with 30 kuruş) in Malošište. In total, he earns 1200 kuruş from job and 390 kuruş from other things.

Household no. 43. Carpenter Miša (f. Bone). Last year he paid vergi with 120 kuruş and aşar for 50 kiye of wheat (12 kuruş) and 80 kiye of corn (16 kuruş). He owns 6 dönüms of land (income 285 kuruş, taxed with 29 kuruş) in Malošište. In total, he earns 550 kuruş from job and 259 kuruş from other things.

Household no. 44. Kiracı Nikola (f. Gospodin). He is kiraci together with his father. Last year he paid a vergi with 67 kuruş and aşar for 100 kiye of wheat (25 kuruş) and 50 kiye of corn (10 kuruş). He pays a tax on alcohol (14 kuruş). He owns 3 dönüms of vineyards (income 90 kuruş per year) and 2 parcels of land of 4 dönüm each (income 300 kuruş, taxed with 35 kuruş) in Sudurun* and Malošište. He keeps 1 bull. In total, he earns 650 kuruş from work and 405 kuruş from other things.

Household no. 45. Carpenter Marinko (f. Stojanča). Last year he paid vergi with 67 kuruş. He earns a total of 350 kuruş from his job.

Household no. 46. Carpenter Stevan (f. Živko). He keeps 1 milking cow (income 12 kuruş) and 2 female calves. He earns a total of 350 kuruş from his job.

Household no. 47. Priest Joakim (f. Bilmarkin*). Last year he paid vergi with 10 kuruş. He owns 3 dönüms of land (income 75 kuruş per year) and rents out 1 shop (income 100 kuruş). In total, he earns 500 kuruş from work and 175 kuruş from other things.

Household no. 48. Carpenter Stojko (f. Đorđe). He works with a business partner at his home. Last year he paid vergi with 85 kuruş. He earns a total of 550 kuruş from his work.

Household no. 49. Carpenter Kole (f. Jovan). Last year he paid vergi of 55 kuruş and aşar for 100 kiye of wheat (25 kuruş) and 40 kiye of corn (8 kuruş). He pays a tax on alcohol (29 kuruş). He owns 2 parcels of vineyards 2 dönüms each (income 150 kuruş per year) and 4 dönüms of land (income 330 kuruş, taxed with 33 kuruş) in Isprazna*. In total, he earns 400 kuruş from work and 447 kuruş from other things.

Household no. 50. Carpenter Stojanko (f. Kole). Last year he paid vergi 29 kuruş. He earns a total of 350 kuruş from his work.

Household no. 51. Household servant Stefan (f. Ivko). Last year he paid vergi with 90 kuruş and aşar for 100 kiye of wheat (25 kuruş). He owns 4 dönüms of land (income 250 kuruş, taxed with 25 kuruş). He earns a total of 120 kuruş from his service i 125 kuruş from other things.

Household no. 52. Grocer Mladen (f. Vlatko). Last year he paid vergi with 90 kuruş and aşar for 100 kiye of wheat (25 kuruş). He pays a tax on alcohol (11 kuruş). He owns 3 dönüms of vineyards (income 75 kuruş per year) and 4 dönüms of land (income 250 kuruş, taxed with 25 kuruş) in Zukve*. He keeps 1 milking cow (income 12 kuruş) and 1 horse. In total, he earns 405 kuruş from job and 312 kuruş from other things.

Household no. 53. Carpenter Stojan (O. Kole). Last year he paid vergi 25 kuruş. He pays tax on alcohol (14 kuruş). He owns 3 dönüms of vineyards (income 30 kuruş per year). In total, he earns 300 kuruş from work and 30 kuruş from other things.

Household no. 54. Weaver Jevta (f. Živko). Last year he paid vergi with 75 kuruş and aşar for 80 kiye of corn (16 kuruş). He pays a tax on alcohol (23 kuruş). He owns 3 dönüms of vineyards (income 150 kuruş per year), 1 dönüm of garden (income 100 kuruş) and 2 dönüms of land (income 160 kuruş, taxed with 16 kuruş) in Malošište. He keeps 2 foals. In total, he earns 350 kuruş from work and 394 kuruş from other things.

Household no. 55. Eskici Toša (f. Bane). Last year he paid vergi with 18 kuruş. He keeps 1 milking cow (income 10 kuruş). In total, he earns 150 kuruş from work.

Household no. 56. Carpenter Mitar (f. Kole). Last year he paid vergi with 42 kuruş and aşar for 50 kiye of wheat (12 kuruş) and 40 kiye of corn (8 kuruş). He owns 2 dönüms of land (income 205 kuruş, taxed with 25 kuruş) in Batušinac. In total, he earns 350 kuruş from job and 143 kuruş from other things.

Household no. 57. Weaver Lila (f. Kosta). Last year he paid vergi with 18 kuruş and aşar for 50 kiye of wheat (12 kuruş). He pays a tax on alcohol (11 kuruş). He owns 2 dönüms of vineyards (income 75 kuruş per year) and 2 dönüms of land (income 125 kuruş, taxed with 13 kuruş) in Isradan*. In total, he earns 120 kuruş from work and 186 kuruş from other things.

Household no. 58. Carpenter Andrija (f. Đoka). Last year he paid vergi 10 kuruş. He pays tax on alcohol (10 kuruş). He owns 2 dönüms of vineyards (income 30 kuruş). In total, he earns 30 kuruş from vineyards and 180 kuruş from other things.

Household no. 59. Household servant Jovan (f. Petar). Last year he paid vergi with 29 kuruş. He pays tax on alcohol (14 kuruş). He owns 2 dönüms of vineyards (income 90 kuruş). In total, he earns 90 kuruş from the vineyards and 150 kuruş from his service.

Household no. 60. Carpenter and priest Ilija (f. Đorđe). Last year he paid vergi 18 kuruş. He earns a total of 250 kuruş from his business.

Household no. 61. Simitçi Jovan (f. Ignjat). Last year he paid vergi with 75 kuruş and aşar for 150 kiye of wheat (37 kuruş) and 50 kiye of corn (10 kuruş). He pays a tax on alcohol (21 kuruş). He owns 3 dönüms of vineyards (income 190 kuruş per year) and 6 dönüms of land (income 475 kuruş, taxed with 48 kuruş) in Malošište. In total, he earns 600 kuruş from work and 616 kuruş from other things.

Household no. 62. Potter Lazar (f. Miljko). Last year he paid vergi with 29 kuruş and aşar for 80 kiye of corn (16 kuruş). He pays a tax on alcohol (32 kuruş). He owns 2 parcels of vineyards of 2 and 3 dönüms (income 195 kuruş per year) and 4 dönüms of land (income 160 kuruş, taxed with 16 kuruş) in Malošište. He keeps 1 horse. He earns a total of 250 kuruş from job and 329 kuruş from other things.

Household no. 63. Crop field worker Ivanko (f. Cvetko). Last year he paid vergi 15 kuruş. He pays tax on alcohol (22 kuruş). He owns 3 dönüms of vineyards (income 225 kuruş per year). In total, he earns 225 kuruş from the vineyards and 120 kuruş from work.

Household no. 64. Carpenter Krsta/Kosta (f. Stojan). Last year he paid vergi 52 kuruş. He pays tax on alcohol (14 kuruş). He owns 2 dönüms of vineyards (income 225 kuruş per year). In total, he earns 350 kuruş from his craft and 225 kuruş from other.

Household no. 65. (Occupation not recorded) Cvetko Nazaren (f. Paun). He paid aşar for 150 kiye of wheat (37 kuruş). He owns 3 dönüms of land (income 375 kuruş, taxed with 37 kuruş) in Isprazna*. His income is 337 kuruş.

Household no. 66. Household servant Rista (f. Janko*). He earns a total of 150 kuruş from service.

Household no. 67. Simitçi Mitar (f. Toša). Last year he paid vergi with 38 kuruş. He pays tax on alcohol (24 kuruş). He owns 3 dönüms of vineyard (income 135 kuruş). In total, he earns 350 kuruş from work and 135 kuruş from other things.

Household no. 68. Simitçi Hrista (f. Ljuben). Last year he paid a vergi with 180 kuruş and aşar for 200 kiye of wheat (50 kuruş) and 100 kiye of corn (20 kuruş). He pays a tax on alcohol (20 kuruş). He owns 3 dönüms of vineyards (income 190 kuruş per year) and 8 dönüms of land (income 700 kuruş, taxed with 70 kuruş) in Bilat*. In total, he earns 650 kuruş from work and 820 kuruş from other things.

Household no. 69. Kürekçi Đorđe (f. Mita). Last year he paid vergi with 110 kuruş. He pays tax on alcohol (8 kuruş). He owns 2 dönüms of vineyards (income 120 kuruş per year) and 2 dönüms of garden (income 90 kuruş). In total, he earns 650 kuruş from work and 210 kuruş from other things.

Household no. 70. Innkeeper Jovan (f. Miladin). Last year he paid vergi with 170 kuruş and aşar for 150 kiye of wheat (37 kuruş) and 100 kiye of corn (20 kuruş). He pays a tax on alcohol (20 kuruş). He owns 6 dönüms of land (income 575 kuruş, taxed with 58 kuruş) in Sudurun*. In total, he earns 1550 kuruş from the tavern and 517 kuruş from other things.

Household no. 71. Gardener Ignjat (f. Stojan). Last year he paid vergi with 115 kuruş and aşar for 100 kiye of wheat (25 kuruş), 50 kiye of barley (10 kuruş) and 40 kiye of corn (8 kuruş). He pays tax on alcohol (11 kuruş). He owns 2 dönüms of vineyards (income 75 kuruş per year), 3 dönüms of land (income 430 kuruş, taxed with 43 kuruş) in Izvor and rents out 1 dönüm of garden (income 50 kuruş). In total, he earns 550 kuruş from work and 512 kuruş from other things.

Household no. 72. A young man (sabi) Janko (f. Vidoje). He has no income, he just lives at his home.

Household no. 73. Crop field worker Todor (f. Veljko). He did not pay vergi last year, yet he paid aşar for 100 kiye of wheat (25 kuruş), 50 kiye of barley (10 kuruş) and 40 kiye of corn (8 kuruş). He pays tax on alcohol (44 kuruş). He owns 4 dönüms of vineyards (income 225 kuruş per year), 3 dönüms of meadows (income 61 kuruş) and 2 parcels of 4 and 9 dönüms of land (income 430 kuruş, taxed with 43 kuruş) in Kalna*. In total, he earns 250 kuruş from work and 667 kuruş from other things.

Household no. 74. Kiracı Ranča (f. Apostol). He keeps 1 foal and 2 bulls. Total income 250 kuruş from work.

Household no. 75. Innkeeper Toša (f. Stanča). Last year he paid vergi with 95 kuruş and aşar for 100 kiye of wheat (25 kuruş) and 40 kiye of corn (8 kuruş). He pays a tax on alcohol (22 kuruş). He owns 1 dönüm of vineyards (income 165 kuruş per year) and 4 dönüms of land (income 330 kuruş, taxed with 33 kuruş) in Malošište. He keeps 1 horse. In total, he earns 550 kuruş from work and 462 kuruş from other things.

Household no. 76. Crop field worker Kole (f. Paun). He pays tax on alcohol (19 kuruş). He owns 2 dönüms of vineyards (income 180 kuruş per year). His total income is 200 kuruş from work and 180 kuruş from other sources.

Household no. 77. Household servant (name not recorded) (f. Marko). His total income is 150 kuruş from service.

Household no. 78. Kiracı Nikola (f. Manča). Last year he paid vergi with 46 kuruş. He owns a house, keeps 2 bulls and a milking cow (income 12 kuruş). In total, he earns 500 kuruş from work and 12 kuruş from the cow.

Household no. 79. Household servant Kole (f. Đole). His total income is 120 kuruş from service.

Household No. 80. Household servant Kole (f. Živko). He did not pay taxes last year. He earns a total of 120 kuruş from his service.

Household no. 81. Household servant Stevan Malča). He did not pay taxes last year. He earns a total of 150 kuruş from his service.

Household no. 82. Carpenter Stanoje (f. Spaša). Last year he paid vergi with 48 kuruş. He owns 3 dönüms of vineyards (income 105 kuruş per year). In total, he earns 450 kuruş from work and 105 kuruş from other income.

Household no. 83. Mane (f. Stanko), he is disabled and mute. He paid aşar for 100 kiye of wheat (25 kuruş), 100 kiye of barley (20 kuruş) and 50 kiye of corn (10 kuruş). He pays the tax on alcohol (43 kuruş). He owns 4 dönüms of vineyard (income 450 kuruş), 1 dönüm of garden (income 30 kuruş) and 10 dönüms of land (income 550 kuruş, taxed with 55 kuruş). In total, he earns 490 kuruş from land and 495 kuruş from other things. In total 985 kuruş (BOA, ML. VRD. TMT d, 11024/3–16).

Conclusion

The statistics of Pop Stanko's mahalle according to the temettuat defter show that its 83 households were headed by 15 people who were carpenters; 12 crop field workers; 12 household servants; 10 kiracıs; 5 innkeepers and potters; 3 simitçis; 2 priests, gardeners, weavers, individuals registered as sabi and 2 with unspecified professions; 1 tailor, grocer, saddle-maker, furrier, kumcu, kürekçi, mutafçı, eskici, simitçi apprentice and 1 disabled person.

Based on this, it is clear that mahalle was mostly inhabited by people whose professions were related to agriculture. In this regard, there were ~20 cultivators of the land grouped in several professions (crop field workers, gardeners, at least 5 out of 10 kiracıs and maybe 1 kürekçi with them). Of all the groups engaged in agriculture, the most income was accumulated by kiracıs, although the defter did not state whether they rented or leased land or real estates. What is also specific for them, compared to other land cultivators, is that kiracıs often possessed various (and numerous) livestock or draft animals, which helped a lot in cultivating land, hence in accumulating income from it. That helped a lot of them to stand out with their income from the rest of the land cultivators. For example, the kiracı with an unrecorded name who lived on number 20 was the richest resident of mahalle, with 750 kuruş earned from primary job and 2022 kuruş drawn from his possessions. As for the land cultivators from the lowest in this group, the crop field workers, it is noticeable that half of them earned 250 kuruş annually from their job, which indicates that the income was probably fixed in some cases.

A kind of a fixed income from a job also applies to the least qualified profession we registered in the mahalle – a household servant. Aside from this job, the majority of people in this group (10) did not have any property or additional source of income. Half of them had an annual income of 150 kuruş, which is again some kind of fixed salary. However, this was still lower than 300 kuruş, which is considered to be the average income of the lower class in the Ottoman Empire at that time (Yükçü, 2017). Among the household servants there were people who had even lower incomes than this. Four household servants earned only 120 kuruş per year, and in their entries in temettuat defters it is often stated that they had not paid vergi for the previous year or the vergi column was simply left blank. Two of the household servants earned annual salary of 200 kuruş from the service. Those who had more than that earned additional profit through agriculture.

In that case, the additional income was always lesser than the income accumulated from their primary profession (Paun at household no. 13 and Jovan at no. 59).

When it comes to a sole profession, the largest number of people were engaged in carpentry (16). It is expected, considering the needs of numerous households in the mahalle and the professions related to agriculture, which dominated among the residents. The need for tools, handles and wooden objects was such that one of the two priests who lived in Pop Stanko's mahalle also was listed among the carpenters (priest Ilija from household no. 60). Priest Ilija was not an isolated case among the clergy. A monk Antim, resident of Pazariçi mahalle in Plovdiv, who was also documented by the temettuat defter in 1845, aside from being a cleric also was an artisan – a furrier with a pretty high income of 2400 kuruş (Todorov, 2024).

As a group, people who accumulated the highest general income were the innkeepers. With 1250 kuruş earned from the tavern and 1339 kuruş from his possessions, innkeeper Filip who lived at no. 7 was the richest of them all and the second richest person in mahalle after unnamed kiracı from no. 20. However, when it comes to profit from tavern as a primary source of profit, the innkeeper Jovan (from no. 70) with 1550 kuruş was the one who ran the best (and the most visited) tavern in mahalle. In the case of innkeepers, the primary profit from tavern and the profit from the secondary sources show huge differences among them. For example, innkeeper Luka (no. 3) accumulated the lowest income from his tavern (550 kuruş), same as innkeeper Toša (no. 75) who ran the worst tavern in the mahalle, probably on its outskirts. But when it comes to income from the secondary sources, 780 kuruş made Luka to be second after Filip among the innkeepers in mahalle by the additional profit.

The fact that some groups were made of a great number of people does not mean that those groups were the best accumulators of profit by default. The groups of 3 or 2 professionals, or even 1 single craftsman could earn more than a decent amount of money. Two of 3 simitçi, Ignjat (no. 61) and Hrista (no. 68), earned 600 kuruş, i. e. 650 kuruş which was more than the innkeepers with the lowest primary income earned (Luka and Toša). Among all craftsmen in mahalle, the data puts furrier Zlatko (no. 35) on top, with 825 kuruş earned from making and selling clothes with furs, as a primary profession. The rest of the small groups of craftsmen and individuals show huge differences in incomes, as much as their professions vary. What might be concluded from that is that those craftsmen were mainly supplying the needs of the households in mahalle rather than exporting their products or providing their services to customers in other parts of Niš.

The temettuat defters do not have religious affiliation as a standard category, but in some cases a note about that might be found next to an entry of a taxpayer (if he stands out from the usual orthodox-Slavic profile in the case of Christian mahalles). For example, Cvetko from household no. 65 was marked as a Nazarene (nasrani), a member of an early Christian sect from 1. century AC. It would be considered awkward or maybe a typo of defter scriber, but also in Niš, in Taverna çiftlik, another person was recorded as Nazarene, too. It was Kole, who lived at the household no. 4. Even with the 2 examples, the case with Nazarenes in Niš might still look like a wrong administrative entry but the fact is that small Christian congregations could be found here and there in the Ottoman Rumelia. For example, Nikolay Todorov identified the Paulikian community in Plovdiv registered by the same temettuat defter from 1844/45 (Todorov, 2024).

Regarding the residential status, out of 83 household owners 10 were recorded as kiracıs, meaning, they came from somewhere and found their place at this mahalle. The reason for having such a visible number of new residents is probably the great Niš uprising which happened in spring of 1841. On the vast territory which stretches in a triangle from Niš to Pirot and Vranje local Serbs in 1841 rose against the violence, discrimination and misdeeds they suffered for a long time from local Muslim landlords and corrupted officials (Ranđelović, 2022). The main reason that made the Serbs burst particularly in 1841 was poorly conducted first temettuat defter (1840/41) which, due to the incompetence of the first muhassıls and corruption of clerks, enlarged their tax obligations and fabricated unsettled debts of many (Öztürk, 2003). As for the previous residence of kiracıs at Pop Stanko's mahalle, some hints (though not necessarily certain) could be the villages where they had their parcels of land. It is the case with 6 out of 10 kiracıs. Five kiracıs had their land at Hrastinče*; 3 at Sudurun*, 2 at Kalna*; 1 sole parcel owned by a kiracı is recorded in Batušinac and Malošište. As for the rest of the residents of mahalle, though not kiracıs, their land parcels were also scattered around Niš, so we can bring following statistics: 1 parcel of land was owned by a resident of mahalle in villages Kalna*, Bilat*, Izvor*, Zukve* and Girašince*; 2 parcels of land in Sudurun*, Isradan* and Suvi Dol; 3 parcels of land in Isprazna*, Hrastinče* and Batušinac. The place where the residents of Pop Stanko's mahalle had the most parcels of land was Malošište, and it records 13 land parcels there. We underline that at some entries land location was not mentioned, so the statistics might be different if that was not the case. As for the toponyms we brought here, it is obvious that most of the population of Pop Stanko's mahalle gravitated to the south of Niš or had their origin from there. The village Malošište dominates in numbers; Batušinac is located close to it, so the same might be the case with at least part of the toponyms mentioned in temettuat defter. From a historical perspective, it makes sense, considering the fact that Malošište, Batušinac and the area around them suffered heavy destruction during the Niš uprising (1841) followed by a significant population drop afterward.

Things changed after the Ottomans announced Hatihumayun in 1856, the decree which strengthened all progressive efforts they were committing since 1839 (Ranđelović, 2022). It was particularly important for further economic and political emancipation of the non-Muslims in the Empire. The benefit from that for the Christians in Niš will be seen when they start building an Orthodox cathedral in the 1850s (Ranđelović, 2015). The location of the huge temple was set in the Serbian Town/Palilula, which obviously could be only Pop Stanko's mahalle. At the same time next to the cathedral, a Christian school was opened, hosting dozens, if not hundreds of Serbian pupils. That way, in less than 15 years Pop Stanko's mahalle was turned from a district at the outskirts of Niš into a political, cultural and religious core of the Serbian community in this city. Such changes affected the character of the mahalle, too. By attracting rich Christian families of traders and craftsmen, once a settlement made dominantly of land cultivators with low and modest income, Pop Stanko's mahalle became a residential district of Serbian pre-industrial bourgeoisie and, after 1878, the oldest historical district of Niš.

References

Başbakanlık Osmanlı Arşivi/ Maliye Nezareti, Varidat Muhasebesi, Temettuât Kalemi Defterleri (BOA, ML. VRD. TMT d)

Başbakanlık Osmanlı Arşivi/ Hariciye Nezareti Siyasi (BOA, HR. SYS)

Güran, T. 2014. *19. Yüzyılda Osmanlı Ekonomisi Üzerine Araştırmalar*, İstanbul, Türkiye İş Bankası Kültür Yayınları.

İnalcık, H. 1978. *The Ottoman Empire: Conquest, Organization and Economy. Collected Studies*. London, Variorum Reprints.

Kordiç. S. 2019. *XIX. Yüzyıl Ortalarında Niş Kazası'nın Sosyal ve Ekonomik Durumu [Yüksek Lisans Tezi]*. İstanbul, İstanbul Üniversitesi – Tarih Anabilim Dalı.

Kütükoğlu, M. S. 1995. Osmanlı Sosyal ve İktisâdî Tarihi Kaynaklarından Temettü Defterleri. *Belleten*, 59 (225), 395–412.

Öztürk, S. 2003. Türkiye'de Temettuat Çalışmaları. *Türkiye Araştırmaları Literatür Dergisi*, 1 (1), 287–304.

Ranđelović, M. 2015. Saborni hram u Nišu: prve decenije (1856–1878). *Peščanik*, 13, 226–235.

Ranđelović, M. 2022. Osmanski upravnici Niša u XIX veku (1799–1878). Niš, Scero Print.

Todorov, N. (2024). Newly Discovered 1845 Ottoman Register of Non-Muslim Population of Plovdiv (Introductory Notes). *Obscured Balkans*, 1, 45–55.

Yükçü, S., Fidancı, N. & Soysal, U. 2017. Osmanlı Devleti'nde Temettuat Defterleri'nin Önemi ve Vergisel Açıdan Değerlendirilmesi: Tire Kazası Örneği. *Muhasebe ve Finans Tarihi Araştırmaları Dergisi*, 7, 170–199.

Endnotes

[1] Although history in the Ottoman period is an integral part of all monographs about Niš from the Interwar period to the present day, so far only two titles have dealt with Ottoman Niš in more detail: the first volume of *Istorija Niša* (Niš, 1983) and the monograph *Osmanski upravnici Niša u 19. veku (1799–1878)* by Milan Ranđelović. When it comes to periodicals and defters as primary sources for the history of Ottoman Niš, the primary (and sole) title is the translated and edited oldest defter of kadıluk of Niš (1498) by a group of authors in *Spomenik* 131/7 (Belgrade, 1992). All these facts emphasize that working on Ottoman documents of this type (defters) is a scientific necessity, even in the case of specific defters, such as temettuats.

[2] Sand seller and dealer

[3] A craftsman who makes sackcloth and similar products woven from goat hair (srb. mutavdžija).

[4] A trader of secondhand clothes and items, a flee marketeer.

[5] When it comes to first temettuat defter from 1840/41, the misstrust of the non-Muslims toward the Ottoman clerks and officials also contributed to this problem. Not really understanding why was the temettuat defter conducted, many people avoided to report their all estate and profit, hence leading the officials to guess or speculate with the income of many taxpayers. It deepened the mistrust of the non-Muslims toward the Ottoman state and caused more serious problems which eventually burst into open uprising.

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NON-MATERIAL INCENTIVES AND THEIR IMPACT ON EMPLOYEE ENGAGEMENT: IMPLICATIONS FOR MODERN MANAGEMENT

Abstract

For the management of an organization, it is of crucial importance how to motivate employees. The necessity of building a good motivation system is a prerequisite for increasing and maintaining competitive advantages. Therefore, in this paper is investigated the impact of non-material incentives, specifically recognition, flexibility, development, and psychological safety, on employee engagement. Using Self-Determination Theory, Herzberg's Two-Factor Theory, and the Job Demands-Resources model, we analysed existing research and conduct a pilot simulation with synthetic data (n = 150, Serbia), aligning with common findings. Recognition and flexibility are shown to have the strongest links with engagement, while psychological safety and development also contribute (Herzberg, 2008). For example, peer recognition programs, which involve regularly acknowledging employee contributions in team settings, have been shown to improve morale and loyalty. Similarly, flexible scheduling options allowing employees to choose their work hours can lead to increased job satisfaction. We used ANOVA and a t-test for gender to validate the results. Besides, its justified using of synthetic data to ensure transparency, respect privacy, and allow replication.

Key words: *employee engagement; non-material incentives; recognition; flexibility; psychological safety*

JEL classification: *O15, M12*

НЕМАТЕРИЈАЛНИ ПОДСТИЦАЈИ И ЊИХОВ УТИЦАЈ НА АНГАЖОВАЊЕ ЗАПОСЛЕНИХ: ИМПЛИКАЦИЈЕ ЗА САВРЕМЕНИ МЕНАЏМЕНТ

Апстракт

За менаџмент једне организације, од кључног значаја је како мотивисати запослене. Неопходност изградње доброг мотивационог система је предуслов

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за повећање и задржавање конкурентских предности. Стога, у овом раду истражује се утицај нематеријалних подстицаја, посебно признања, флексибилности, развоја и психолошке сигурности, на ангажовање запослених. Користећи теорију самоопредељења, Херцбергову двофакторску теорију и модел захтева и ресурса посла, анализирали смо постојећа истраживања и спровели пилот симулацију са синтетичким подацима (н = 150, Србија), што се поклапа са уобичајеним резултатима. Показало се да признање и флексибилност имају најјаче везе са ангажовањем, док психолошка сигурност и развој такође имају свој допринос (Херцберг, 1968). На пример, показано је да програми признавања од стране колега, који укључују редовно вредновање доприноса запослених у тимском окружењу, побољшавају морал и лојалност. Слично томе, флексибилне могућности распореда који омогућава запосленима да бирају своје радно време могу довести до повећаног задовољства послом. У раду је коришћена ANOVA и т-тест за пол да би се валидирали резултати. Поред тога, оправдано је коришћење синтетичких података како би се осигурала транспарентност, поштовала приватност и омогућила репликација. Рад се завршава менаџерским препорукама, 12-недељним планом имплементације и алатима за мерење.

Кључне речи: *ангажованост запослених; нематеријални подстицаји; признање; флексибилност; психолошка сигурност*

Introduction

Modern companies increasingly attach importance to organizational change, not because managers and employees have a natural inclination towards it, but because it is a necessary condition for survival in a dynamic business environment (Stanujkić et al., 2024; Popović et al., 2021a; 2021b). Strategic planning and organizing change are key steps in the change management process and can significantly influence their successful outcome (Kotter et al., 2021).

The field of human resource management is continuously developing and improving, following new trends, challenges and transformations in the modern economy. In this context, numerous structural and functional changes have occurred. As one of the key executive functions of an organization, human resource management aims to manage employees as effectively as possible, in order to ensure the achievement of both organizational and individual goals (Paauwe & De Voorde, 2025; Urošević et al., 2016).

Imagine a company spending millions annually on specialized benefits and competitive salaries, yet watching its employee engagement scores stagnate year after year. Despite this significant investment in compensation, many organizations achieve only modest and inconsistent gains in employee engagement. Evidence suggests non-material incentives, those without financial reward, can provide stronger, context-sensitive effects on engagement and performance. This article combines theory and evidence to demonstrate the relationship between these incentives and engagement in practice.

Building on classical foundations, Daniel Pink emphasizes three essential dimensions of intrinsic motivation: autonomy, mastery, and purpose (Pink, 2009a; 2009b). Autonomy

reflects the human desire for self-direction, aligning with the need for workplace flexibility and autonomy in decision-making. Mastery denotes the pursuit of continuous improvement and learning, resonating with professional development opportunities. Purpose involves connecting work to a larger mission, fostering meaning and commitment. These dimensions complement Self-Determination Theory and Herzberg's motivators, underscoring how non-material incentives fuel engagement in modern organizations (Herzberg, 2008).

Pink's framework situates intrinsic drivers at the center of modern engagement. Unlike Herzberg or Maslow (Maslow, 1943), who positioned recognition and growth as secondary motivators, Pink argues that financial incentives only create short-term compliance, while autonomy and purpose unleash creativity, persistence, and engagement. (Pink, 2009a; 2009b) For instance, organizations that allow employees to design part of their schedule or dedicate time to projects of personal significance often report higher levels of innovation and commitment. (https://www.gartner.com/en/articles/the-secret-to-productive-employees-a-radical-shift-in-work-flexibility).

Maslow's hierarchy of needs positions self-actualization as the pinnacle of motivation, which is closely linked to mastery and a sense of purpose (Maslow, 1943). Amabile highlights that creativity and intrinsic motivation thrive when individuals are given autonomy and recognition (Amabile, 2018) Schein argues that organizational culture and leadership shape the motivational climate, making psychological safety and fairness critical to sustaining engagement (Schein, 2010).

Self-Determination Theory says autonomy, competence, and relatedness drive internal motivation (Deci & Ryan, 2013) Recognizing these needs has become crucial in today's workplace, where employees seek deeper fulfilment from their roles. Herzberg's Two-Factor Theory lists motivators such as recognition, achievement, and growth as key, placing non-material incentives in this category (Herzberg, 2008). This becomes particularly relevant as organizations aim to maintain engagement amid evolving employee expectations. The Job Demands–Resources model explains how job resources, such as autonomy, feedback, support, and development, foster motivation and buffer job demands (Bakker & Demerouti, 2007). In the current climate, utilizing this model helps to understand and manage work-related stress, thereby enhancing employee satisfaction. Across these models, incentives that build psychological resources—rather than add external rewards—improve vigor, dedication, and absorption (Khan et al., 2022). These insights underscore the importance of non-material incentives in crafting a resilient and motivated workforce.

Materials and Methods

A cross-sectional survey is used to measure employee engagement (UWES-9 - Utrecht Work Engagement Scale) and perceived non-material incentives (recognition, flexibility, development, psychological safety). To focus on methodology, a synthetic data is analysed (n=150) matching distributions from Serbian organizations (IT, telecom, banking, retail). The use of synthetic data was chosen to ensure data privacy and facilitate replicability; however, it is worth noting that this approach may limit the generalizability of the findings to real-world settings. Variables were assessed using a 1–5 Likert scale. UWES-9 measured vigor, dedication, and absorption. Non-material incentives included statements like 'I receive work acknowledgment,' 'I manage my work hours,' 'I get growth opportunities,' and 'I can

express ideas at work,' all rated on the same scale. We report descriptive statistics, Pearson correlations, OLS regression with demographic controls, and run t-tests for gender and ANOVA for age groups.

Results

Figure 1 shows the structure of the sample according to age groups. The largest share belongs to the 18- to 30-year-old group, which makes up 39% of the sample. Next in terms of representation is the 31 to 45 age group with 35%, while the 46 to 60 age group is the least represented with 26%.

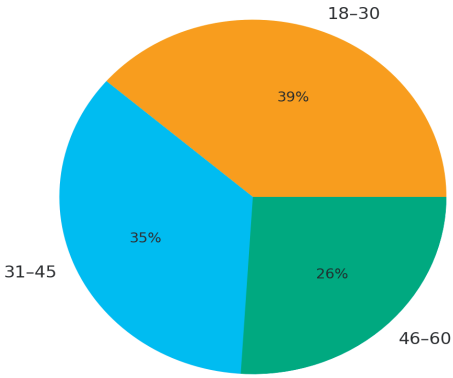

Figure 1: Sample structure by age group

Figure 2 shows the average ratings (Likert scale 1-5) of the four types of non-material incentives.

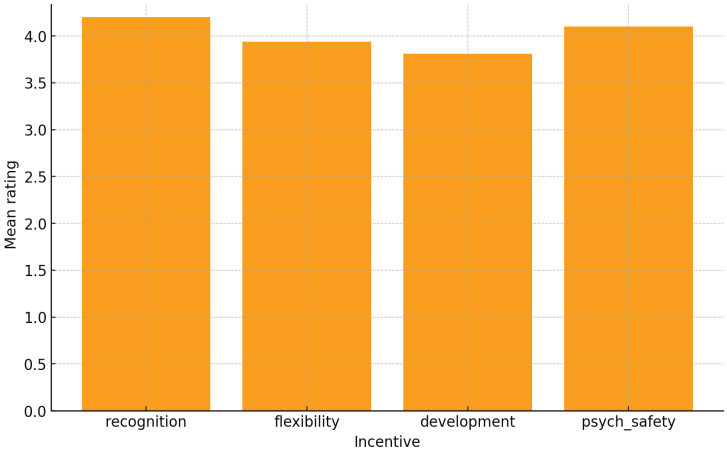

Figure 2: Mean ratings of non-material incentives

Table 1 shows descriptive statistics for five variables used on a Likert scale (1–5): recognition (Mean = 4.2, SD = 0.63), flexibility (Mean = 3.94, SD = 0.73), development (Mean = 3.81, SD = 0.72), psychological safety (Mean = 4.1, SD = 0.65), and engagement (Mean = 4.15, SD = 0.65). All variables have high average scores, with minimum values between 2.0 and maximum values of 5.0. Standard deviations indicate the relative consistency of responses across participants, with recognition having the lowest standard deviation (0.63) and flexibility the highest (0.73).

Table 1: Descriptive statistics

Variable	Mean	SD	Min	Max
recognition	4.2	0.63	3.0	5.0
flexibility	3.94	0.73	2.0	5.0
development	3.81	0.72	2.0	5.0
psych_safety	4.1	0.65	2.0	5.0
engagement	4.15	0.65	3.0	5.0

Source: Author's calculation

The table 2 shows the Pearson correlation matrix between the variables recognition, flexibility, development, psychological safety and engagement. Most of the correlations between the variables are weak but positive, suggesting that there is a mild but stable interrelationship. For example, recognition and engagement have a correlation of 0.34, indicating that a higher level of recognition may contribute to greater engagement. Also, the correlation between flexibility and engagement (0.35) shows that more flexible working conditions can positively affect employee engagement. Although correlations are generally weak, these results indicate that factors such as familiarity, flexibility, and psychological safety may have positive, albeit small, effects on engagement, which is certainly encouraging for further research.

Table 2: Pearson correlation matrix

Variable	recognition	flexibility	development	psych_safety	engagement
recognition	1.0	-0.05	0.04	0.06	0.34
flexibility	-0.05	1.0	0.05	0.07	0.35
development	0.04	0.05	1.0	-0.0	0.13
psych_safety	0.06	0.07	-0.0	1.0	0.22
engagement	0.34	0.35	0.13	0.22	1.0

Source: Author's calculation

Table 3 presents the results of the OLS regression predicting employee engagement using demographic characteristics and non-material incentives as predictors. Recognition (coefficient = 0.348, $p < 0.001$), flexibility (coefficient = 0.306, $p < 0.001$), and psychological safety (coefficient = 0.176, $p = 0.015$) show statistically significant positive effects on engagement, while development (coefficient = 0.086, $p = 0.189$) is not significant. The reference age group is 18–30 years, which represents the largest share

of the sample (39%). The other age groups (31–45 and 46–60) do not differ significantly from this baseline, indicating that engagement levels are consistent across age categories. The reference gender category is female (50% of the sample), and male employees (50% of the sample) show no significant difference in engagement (coefficient = 0.047, p = 0.621). Sectoral variables (IT, Retail, Telecom) are not statistically significant, which suggests that sector affiliation does not substantially influence engagement once non-material incentives are considered. The intercept (0.437, p = 0.425) reflects the expected engagement level for the reference categories (female, 18–30 years, outside IT/Retail/Telecom) but is not statistically significant and therefore serves only as a baseline reference point in the model.

Table 3: OLS regression predicting engagement

Term	Coefficient	CI Low	CI High	p-value
Intercept	0.437	-0.642	1.515	0.425
C(age_group)[T.18–30]	Reference			
C(age_group)[T.31–45]	-0.025	-0.247	0.197	0.825
C(age_group)[T.46–60]	-0.104	-0.341	0.134	0.389
C(gender)[T.Female]	Reference			
C(gender)[T.Male]	0.047	-0.141	0.236	0.621
C(sector)[T.IT]	0.058	-0.216	0.332	0.677
C(sector)[T.Retail]	0.076	-0.195	0.347	0.58
C(sector)[T.Telecom]	-0.148	-0.434	0.137	0.307
recognition	0.348	0.202	0.493	0.0
flexibility	0.306	0.176	0.437	0.0
development	0.086	-0.043	0.216	0.189
psych_safety	0.176	0.034	0.319	0.015

Source: Author's calculation

Discussion

By merging classical theories with Pink's modern approach, this study demonstrates that sustainable engagement arises when employees experience autonomy, mastery, purpose, and psychological safety together (Pink, 2009a; 2009b). For managers, the implication is clear: financial incentives alone are insufficient to motivate employees. A holistic system of recognition, meaningful work, and supportive culture is required to unlock long-term motivation. Pink's model positions modern organizations at a crossroads: continue relying on outdated extrinsic motivators, or embrace intrinsic, human-cantered incentives that align with knowledge economies (https://medium.com/@felixdavidenko/rethinking-motivation-3cc596cafd2a). The findings align with established theory: recognition and flexibility are most strongly linked to engagement, and psychological safety and development also play a significant role (Imran et al., 2025; Kgarimetsa & Naidoo, 2024). Although the data are synthetic, the analysis uses standard field study methods, allowing future researchers to replicate the process. Managers should focus on ongoing recognition, structured autonomy, and leadership that builds psychological safety (Loudoun et al., 2025; Jose et al., 2024; Bano et al., 2024).

Conclusion

This study examined the role of non-material incentives—recognition, flexibility, development, and psychological safety—in shaping employee engagement. By integrating established motivational frameworks, including Self-Determination Theory, Herzberg's Two-Factor Theory, and the Job Demands–Resources model, the research provided a comprehensive theoretical foundation for understanding how intangible resources affect motivation and performance. The analysis, based on synthetic data reflecting organizational contexts in Serbia, confirmed that recognition, flexibility, and psychological safety are statistically significant drivers of engagement, while development did not show a significant impact. Furthermore, demographic variables such as age, gender, and sector did not demonstrate notable differences, which indicates that non-material incentives exert a consistent influence across different groups of employees. The contribution of this research is twofold. Theoretically, it reinforces the central role of intrinsic motivators in sustaining employee engagement, highlighting the enduring relevance of non-material factors in contemporary management. Practically, the study offers empirical evidence that intangible incentives can serve as powerful mechanisms for strengthening commitment and resilience within organizations. While the use of synthetic data ensured transparency and replicability, it also limits the generalizability of the findings, underscoring the need for future validation in field settings. Nevertheless, the results provide a strong basis for further exploration of how recognition, flexibility, and psychological safety can be systematically integrated into organizational culture. In conclusion, the study affirms that non-material incentives are not secondary benefits but fundamental drivers of engagement that support both individual motivation and long-term organizational success. The study utilizes synthetic data for transparency; however, real-world validation is necessary. Using synthetic data can sometimes limit the direct applicability of findings to actual workplace environments, as synthetic data may not fully capture the complex and variable conditions inherent in real-world settings. This might lead to challenges in replicating findings as companies implement strategies emanating from these insights, particularly because synthetic data lacks the nuanced circumstantial influences present in real data. Future research should pre-register studies with diverse samples, experimentally test non-material incentives, and examine the cultural and long-term effects. Field studies in various industries can demonstrate how non-monetary incentives function in different settings. Tracking engagement over time reveals sustainability. Research on remote workers or those in the gig economy can uncover unique engagement factors for these groups.

References

Amabile, T. M. (2018). Creativity in context: Update to the social psychology of creativity. Routledge.

Bakker, A. B., & Demerouti, E. (2007). The job demands-resources model: State of the art. Journal of managerial psychology, 22(3), 309-328.

Bano, S., Ji Zu, L., & Imran, M. (2024). Relationship Between Ethical Leadership and Job Performance in Non-Profit Organizations of Pakistan: Mediating Role of Psychological Safety. Public Integrity, 1-22.

Deci, E. L., & Ryan, R. M. (2013). Intrinsic motivation and self-determination in human behavior. Springer Science & Business Media.

Herzberg, F. (2008). One more time: How do you motivate employees?. Harvard Business Review Press.

https://medium.com/@felixdavidenko/rethinking-motivation-3cc596cafd2a (13.05.2025)

https://tivazo.com/blogs/employee-motivation-theories-workplace-hacks/ (23.05.2025)

https://www.gartner.com/en/articles/the-secret-to-productive-employees-a-radical-shift-in-work-flexibility (23.05.2025)

Imran, U. D., Ghazwan, M. F., & Firmansyah, F. (2025). The effect of recognition and appreciation on employee motivation and performance. Economics and Digital Business Review, 6(1), 1-18.

Jose, G., PM, N., & Kuriakose, V. (2024). HRM practices and employee engagement: Role of personal resources-a study among nurses. International Journal of Productivity and Performance Management, 73(1), 1-17.

Kgarimetsa, T. S., & Naidoo, C. (2024). Effect of employee recognition and flexible working arrangement on Generation Z retention. SA Journal of Human Resource Management, 22, 1-11.

Khan, R., Neveu, J. P., Murtaza, G., & Khan, K. U. (2022). Impact of psychological resources on employee engagement: The mediating role of positive affect and ego-resilience. Sage Open, 12(2), 21582440221089971.

Kotter, J. P., Akhtar, V., & Gupta, G. (2021). Change: How organizations achieve hard-to-imagine results in uncertain and volatile times. John Wiley & Sons.

Loudoun, R., Doshi, H., Townsend, K., Cafferkey, K., & Robertson, A. (2025). The Critical Role of Psychological Risk and Safety in Eliciting Worker Well-Being. Asia Pacific Journal of Human Resources, 63(2), e70009.

Maslow, A. H. (1943). A theory of human motivation. Psychological review, 50(4), 370.

Paauwe, J., & Van De Voorde, K. (2025). Bridging the research-practice gap in modern human resource management. Human Resource Management Review, 35(2), 101076.

Pink, D. (2009b). The Puzzle of Motivation. TED Global.

Pink, D. H. (2011a). Drive: The surprising truth about what motivates us. penguin.

Popović, M. (2021b). An MCDM approach for personnel selection using the CoCoSo method. Journal of process management and new technologies, 9(3-4), 78-88.

Popović, M., Popović, G., & Karabašević, D. (2021a). Determination of the importance of evaluation criteria during the process of recruitment and selection of personnel based on the application of the SWARA method. Ekonomika, 67(4), 1-9.

Schein, E. H. (2010). Organizational culture and leadership (Vol. 2). John Wiley & Sons.

Stanujkić, M., Popović, G., Karabašević, D., Šarčević, M., Stanujkić, D., & Novaković, S. (2024). Approach to the personnel selection in a group decision-making environment based on the use of the MULTIMOORA and PIPRECIA-S methods. BizInfo Blace, 15(1), 19-26.

Urošević, S., Milijić, N., Maljković, N. Đ., & Karabašević, D. (2016). Indicators of motivation and employee satisfaction in public enterprise–case study of PE "Post of Serbia". Industrija, 44(3).

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THE ERA OF ROBOTICS, AI, AND SERVICE AUTOMATION: SMART PORTS AS A MODEL FOR INTERNATIONAL TRADE

Abstract

This study aimed to investigate the application and impact of Robotics, Artificial Intelligence, and Service Automation (RAISA) technologies within the port and maritime logistics sector. Through a comprehensive analysis of existing literature and empirical studies, the research employed a systematic review methodology to synthesize findings across operational, strategic, and human dimensions.

The study concluded that RAISA technologies significantly enhance port operational efficiency by optimizing vessel traffic, automating container handling, and reducing waiting times and costs. Key findings also underscore their role in advanced risk prediction, improved economic competitiveness through dynamic pricing, and notable gains in environmental sustainability. However, successful implementation hinges on overcoming challenges related to system integration, workforce reskilling, and managing customer acceptance. The research affirms that strategic RAISA adoption is imperative for ports to thrive.

Key words: *Robotics, AI, Service Automation, Smart Ports, International Trade.*

JEL classification: *L91, O33, M15, Q55, F18.*

ЕРА РОБОТИКЕ, ВЕШТАЧКЕ ИНТЕЛИГЕНЦИЈЕ И АУТОМАТИЗАЦИЈЕ УСЛУГА: ПАМЕТНЕ ЛУКЕ КАО МОДЕЛ МЕЂУНАРОДНЕ ТРГОВИНЕ

Апстракт

Ова студија имала је за циљ да истражи примену и утицај технологија роботике, вештачке интелигенције и аутоматизације услуга (RAISA) унутар сектора поморске логистике и лука. Кроз свеобухватну анализу постојеће литературе и емпиријских студија, истраживање је применило методологију систематског прегледа како би синтетизовало налазе у оперативним, стратешким и људским димензијама.

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Студија је закључила да RAISA технологије значајно побољшавају оперативну ефикасност лука оптимизацијом саобраћаја бродова, аутоматизацијом руковања контејнерима и смањењем времена чекања и трошкова. Кључни налази такође наглашавају њихову улогу у напредном предвиђању ризика, побољшаној економској конкурентности кроз динамичко одређивање цена и значајним добитницима у еколошкој одрживости. Међутим, успешна имплементација зависи од превазилажења изазова везаних за интеграцију система, преквалификацију радне снаге и управљање прихватањем од стране корисника. Истраживање потврђује да је стратешка примена RAISA технологија императив за просперитет лука.

Кључне речи: *Роботика, Вештачка интелигенција, Аутоматизација услуга, Паметне луке, Међународна трговина.*

Introduction

There is an urgent need for more research on the applications of Artificial Intelligence (AI), which is one of the latest technological trends impacting our daily lives. Consequently, various industries are increasingly pursuing the enhancement of their applications in robotics and automation technologies to deliver meticulously flawless services in an engaging manner (Similar to the fields of education, industry, agriculture, logistics, transportation, tourism, commerce, and finance…) (Ivanov & Webster, 2017, p. 1). By leveraging artificial intelligence, these sectors aim to establish a unique and unparalleled experience for their customers.

However, research in this area remains limited across various sectors. This lack of research underscores the importance of focusing on how modern technologies can be utilized to improve operational efficiency and increase customer satisfaction. Institutions need to explore the potential of AI and robotics to meet growing market demands and enhance the services provided. Promoting research in this field can contribute to developing effective strategies, helping to boost competitiveness in the face of global challenges.

Scholarly investigations have indicated that Robotics (R), Artificial Intelligence (AI), and Service Automation (SA) (collectively referred to as RAISA) technologies have emerged as vital and dependable assets for organizations across multiple sectors. This trend of adoption is on the rise, driven by the increasing recognition of these technologies as critical drivers for innovation and profitability enhancement. Nations such as Japan, the United Kingdom, the United States, and China are at the forefront of this technological evolution, committing substantial financial resources, amounting to billions of dollars annually, towards the development and implementation of RAISA solutions.

This investment reflects these countries' commitment to improving their competitiveness through technological innovation. It also highlights the significance of RAISA in enhancing operational efficiency and reducing costs (Meziane & Bouguetaia, 2023, p. 7), contributing to the improvement of service quality provided to customers.

The increasing reliance on RAISA is considered a strategic step toward a more advanced and innovative future, contributing to the creation of a more effective work environment across various industries (Yassin, Gharieb, & Saad, 2022, p. 52).

From the aforementioned, it is imperative for us as researchers, academics, entrepreneurs, and consumers to strive for an understanding of the changes brought about by this electronic revolution. We must proactively anticipate its consequences in order to navigate them effectively. Humanity should not remain passive but should actively seek to manage and frame these changes. There is a consensus that this transformation is unlike any previous experiences, such as the industrial revolution, economic crises, globalization, world wars, or the Cold War. The current issue has not waited for our academic contributions; rather, it has preceded them and shown a clear impact on societies, behaviors, and policies.

Therefore, this study aims to enhance understanding as a foundation for formulating policies that maximize benefits and positives while minimizing potential risks and deviations.

Literature review

The existing body of research on smart ports demonstrates a clear evolution from exploring technological feasibility to examining the strategic, human, and procedural factors that underpin successful digital transformation. Scholars have approached this field from various methodological angles, providing a multi-faceted understanding of the opportunities and challenges.

A significant strand of literature focuses on the tangible operational benefits and technical implementation of artificial intelligence. For instance, (Korostin, 2025) developed AI solutions for port automation utilizing natural language processing and time-series analysis. The study's findings indicated that these technologies can significantly enhance container management, coordinate vessel movements, and predict operational risks with high accuracy, leading to a notable reduction in costs and waiting times. Similarly, (Foster & Rhoden, 2020) provided a regional case study, highlighting the growing importance of AI in Caribbean logistics for improving efficiency and revenue. Their research noted a positive willingness among industry participants to adopt such technologies, despite acknowledged challenges related to resources and awareness. However, these studies also reveal consistent impediments, including the difficulty of integrating new systems with traditional infrastructure and the critical need for employees to develop new technical skills.

Complementing this technical focus, another group of studies employs advanced statistical modeling to investigate the deeper drivers and strategic frameworks necessary for adoption. (Ghazaleh, 2023) investigated the business drivers behind AI transformation in ports using Exploratory Factor Analysis (EFA), Confirmatory Factor Analysis (CFA), and Structural Equation Modeling (SEM). The research established that fundamental drivers like enhancing productivity and predictive capabilities are paramount, but their success is contingent upon rigorous guarantees of reliability and interpretability. The study cautioned against the consequences of immature applications and proposed a methodological framework to mitigate implementation risks. Expanding on the

strategic perspective, (Kuo, Huang, & Chen, 2022) explored the integration of AIoT and blockchain to create sustainable operational schemes. Their use of SEM allowed them to analyze the key factors influencing adoption, concluding that investment in smart port technology is a critical strategic decision even in regions with low labor costs. The study identified operator attitudes and motivations as pivotal, ultimately providing a valuable framework for implementing smart, sustainable ports by outlining the key drivers of success.

Concept of RAISA Technologies

The reliance on robots, artificial intelligence, and automation represents the realization of goals that were once deemed science fiction in the recent past (Agah, Cabibihan, Howard, Salichs, & He, 2016). "RAISA" is a term coined by researchers (Ivanov & Webster, 2017, p. 1). This was the first attempt to study RAISA in the tourism and hospitality sector from a social sciences perspective. Their research focuses on analyzing theoretical issues related to the adoption of these technologies in tourism, as well as examining the principles of service automation and societal attitudes toward robots. Their studies also address the impact of RAISA on business operations.

Robots can be characterized as "physically intelligent systems" endowed with varying levels of autonomy, mobility, and sensory perception, which enable them to execute designated tasks effectively. The term autonomy pertains to the robot's capacity to perform its functions independently, without reliance on human oversight. This autonomous capability significantly enhances the robot's operational efficiency and its adaptability in managing a diverse array of tasks across multiple environments (Chen & Hu, 2013, pp. 164-165), The (International Organization for Standardization, 2012) classifies robots into industrial and service categories based on their economic application. Industrial robots are defined as programmable, multipurpose manipulators with three or more axes, designed for fixed or mobile use in industrial automation. In contrast, service robots perform beneficial tasks for humans or equipment outside industrial settings, with the categorization determined solely by the application domain rather than the robot's technical design.

The integration of robotic systems into industrial and service sectors represents a significant technological shift with profound operational implications. The following table systematically outlines the key advantages and disadvantages associated with the deployment of robots, providing a balanced overview to support strategic decision-making regarding automation investments.

The theoretical conceptualization of artificial intelligence denotes a system's capacity to identify problems, engage in analytical reasoning, and execute precise actions to resolve them—essentially emulating human cognitive functions. AI-enabled systems possess advanced capabilities for autonomous learning and dynamic interaction with external environments, including nuanced communication with users, processing of contextual messages, and adaptive responses to real-world events and stimuli (Huang & Rust, 2018, p. 156). Artificial Intelligence (AI) refers to computational systems designed to exhibit intelligent behavior by processing information, learning from data, and making decisions or responding to stimuli in a manner that emulates human cognitive functions (Poole & Mackworth, 2010, p. 49). AI appears in various forms, whether human-like

or non-human, such as automated services capable of simulating or performing human tasks (Mellit & Kalogirou, 2008, pp. 588-604). AI has rapidly evolved from performing simple tasks, such as voice assistants, to the ability to carry out more complex social functions, such as recognizing and interacting with customer emotions.

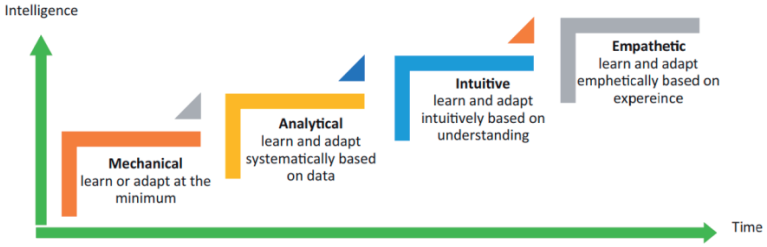
Figure 1: Taxonomy of Robots and Automated Systems.

	Category	Core Definition	Key Characteristics	Examples	Exceptions & Notes
Based on (ISO, 2012)	**Industrial Robot**	An automatically controlled, reprogrammable, multipurpose manipulator for industrial automation.	- üüüüüüüü=ü axes - Fixed or mobile - Designed for industrial tasks - Physical alteration may be needed to adapt	Articulated arms for welding, assembly, or painting on a production line.	The definition is based strictly on the application within the industrial automation sector.
	Service Robot	A robot that performs useful tasks for humans or equipment, excluding industrial automation applications.	- Defined by its **sector of application** (services) - Task-oriented, not design-oriented	An articulated robot used for serving food in a restaurant.	A robot physically identical to an industrial model is classified as a service robot if used outside industrial automation (e.g., food service).
Based on Working Definitions	**Service Robot**	A physical, mobile device with autonomy performing tasks professionally in the service sector.	- **Physical device** - Mobile - Some autonomy - Professional use in services	Delivery robots in hospitals, cleaning robots in airports, automated guided vehicles in warehouses.	Explicitly excludes software-based systems like chatbots.
	Social Robot	A robot able to interact and communicate with humans, other robots, and the environment.	- Designed for interaction and communication - Can be a subset of service or personal robots	Customer-service robots (e.g., a concierge robot), companion robots.	Can be for professional (service) or personal use. Not all service robots require social capabilities.
	Cobot (Collaborative Robot)	A robot designed to work alongside humans in a shared workspace.	- Designed for physical collaboration and safety - Focus on proximity to humans	A robot that assists a human worker with lifting heavy parts in a workshop.	A design distinction crucial in industry. For service robots, working near humans is often the default assumption.
	Bot / Chatbot	A software interface that connects users with services or performs automated digital tasks.	- **Purely software** - No physical form - Automates digital routines or provides an interface	Web crawlers, automated customer support chatbots, virtual assistants like ChatGPT.	**Excluded** from the working definition of a service robot because it is not a physical device.

Source: (Sostero, 2020, pp. 7-10)

Information Technology (IT) is a key factor that has facilitated the entry of AI into the business world. AI has become an effective tool for streamlining internal processes within companies and managing external transactions with customers in various contexts, whether personal or impersonal (Prentice, Weaven, & Wong, 2020).

Figure 2: The four intelligences.



Source: (Huang & Rust, 2018, p. 158)

The figure 2 presents a sophisticated analytical framework for artificial intelligence, classifying it into four main categories that escalate in complexity and proximity to human capabilities. The classification begins with mechanical intelligence, representing the foundational layer for automation and routine tasks, and progresses to analytical intelligence based on big data processing and statistical prediction. It then ascends to intuitive intelligence, which mimics human creative thinking in solving complex problems, reaching its peak with empathic intelligence that adds a human dimension to interactions through understanding and responding to emotions. The figure clearly highlights the functional integration between these layers and how they operate sequentially and interconnectedly to achieve near-comprehensive intelligence, where analytical capabilities feed intuitive intelligence, and intuitive flexibility paves the way for advanced emotional interactions.

Service automation refers to the use of machines to complete a series of predefined or reprogrammable tasks in service delivery. The earliest manifestations of service automation included ATMs, conveyor belts, self-checkout systems in stores, and vending machines (Law, Buhalis, & Cobanoglu, 2014, pp. 730-741).

Opportunities for Artificial Intelligence, Robotics, and Automation in ports

As the development of smart ports accelerates, the transition toward global port intelligence is becoming a defining trend in the modernization of maritime operations. As the development of smart ports accelerates, the transition toward global port intelligence is becoming a defining trend in the modernization of maritime operations.

Fully automated terminals deliver four core advantages: they significantly reduce the impact of adverse weather on terminal productivity, improve safety by limiting the number of personnel required in operational zones, diminish labor intensity and associated human errors, and cut down overall labor expenses. These advantages provide a clear set of key performance indicators for evaluating the efficiency and effectiveness of next-generation port infrastructure (Kuo, Huang, & Chen, 2022).

Table 2: Applications of AI and Big Data in Smart Ports

Technology	Application & Function	Key Benefit	Source
Automatic Identification System (AIS)	Uses AI to analyze real-time ship data (position, speed, course) for predicting traffic flow and optimizing berth allocation.	Enables proactive planning and reduces vessel waiting times.	(Huang, Li, Zhang, & Liu, 2020)
Artificial Neural Networks (ANNs)	Employs deep learning for optical character recognition (OCR) to automatically identify and verify container numbers.	Streamlines logistics, reduces errors, and accelerates container processing in the supply chain.	(Cepowski & Chorab, 2021)
Automated Guided Vehicles (AGVs)	AI-powered, self-navigating vehicles that transport containers within automated terminals without human drivers.	Increases operational efficiency, safety, and enables 24/7 unmanned container movement.	(Kosiek, Kaizer, Salomon, & Sacharko, 2021)
Autonomous Robots	Used for inspecting ship hulls and underwater port infrastructure for damage or security threats. Also developed for automated container stacking and retrieval.	Enhances port security through consistent monitoring and automates labor-intensive, physical tasks.	(Blokus & Dziula, 2019) (Yuan, et al., 2010)
Smart Grids	AI-managed energy systems that integrate renewable sources (e.g., wind, solar) to power port operations dynamically.	Promotes environmental sustainability and reduces the carbon footprint of port activities.	(Kanellos, Volanis, & Hatziargyriou, 2017)

Source: (Kuo, Huang, & Chen, 2022, p. 33)

Impact on Productivity and Performance

AI algorithms allow ports to monitor vessel traffic, manage schedules, assess container conditions, and determine resource needs in real-time. This functionality improves operational efficiency, minimizes delays, and facilitates data-driven decision-making using immediate, vital information (Korostin, 2025, pp. 74-76). RAISA technologies, leveraging historical data and machine learning, can be employed to improve operational efficiency and shorten loading periods. Consequently, RAISA provides greater flexibility in reducing wait times and accelerating the delivery of goods among various stakeholders, including suppliers and customers (Ghazaleh, 2023, p. 80). Artificial intelligence enhances the coordination of vessel movements within ports, effectively preventing congestion and optimizing the use of available berths. This capability is particularly crucial for large ports operating at high throughput rates, ensuring continuous operations and boosting overall productivity.

Furthermore, RAISA is expected to develop advanced digital dashboards that will replace traditional communication systems based on radio and radar between ship crews, port pilots, and terminal operators (Huang, Wang, Xu, Zhu, Tang, & Xu, 2018, pp. 1-5).

(Lestari, 2022, October) identifies key drivers of employee performance in technology-driven work environments. The research establishes that employee self-efficacy—an

individual's belief in their own capability—is a significant positive predictor of performance. Furthermore, the quality of the relationship between employees and their supervisors is emphasized as a critical factor in achieving higher performance levels. The study also confirms that a positive attitude towards the adoption of smart technology directly enhances employee performance. These findings highlight the importance of fostering a supportive work environment that builds self-confidence, promotes strong supervisory relationships, and encourages the integration of advanced technologies to improve overall performance and achieve sustainable organizational success.

Predicting imminent risks

RAISA's ability to predict delays and plan operations is a critical application area. The system analyzes historical and current temporal data to identify operational risks related to weather conditions, terminal congestion, or infrastructure failures. For instance, RAISA can forecast peak operational periods in advance and suggest proactive measures such as rescheduling vessels, rerouting shipments, or increasing workforce in critical areas. Additionally, RAISA enhances the performance of cranes, loading platforms, and autonomous vehicles through precise and timely operational planning (Korostin, 2025). These integrated functions enable ports to optimize resource utilization and mitigate financial losses caused by operational disruptions. By leveraging data-driven insights, RAISA helps ensure smoother operations, ultimately contributing to greater efficiency and productivity within the port environment. This comprehensive approach not only addresses immediate challenges but also supports long-term strategic planning for enhanced resilience in port operations.

The potential of RAISA and machine learning in improving port risk management is highlighted through the analysis of unstructured data along with internal and external operational data. These technologies can provide accurate predictive insights to enhance operational efficiency, reduce wait times, and mitigate operational risks. Additionally, AI-based models offer effective tools for monitoring systemic risks across different ports, thereby enhancing safety and reducing costs. The development of these models is a crucial step toward digitizing maritime risk management and ensuring more resilient supply chains (Van Thiel & Van Raaij, 2019, p. 167).

Impact on Operations

Automating port operations, including loading and unloading, is crucial for saving time and labor while reducing costs and workplace accidents. This efficiency attracts customers, enhancing satisfaction and loyalty. Automation also improves customs processes, speeding up clearance and decreasing bureaucratic inefficiencies and corruption. The reliance on robots and automated systems boosts service capacity, allowing ports to handle more vessels and cargo simultaneously. Continuous operation without human limitations facilitates better scheduling and planning. Additionally, this shift fosters environmental sustainability by minimizing resource consumption and waste, leading to more efficient and responsible port operations (Stuart-Hill, Vienna, p. 46).

Impact of RAISA on Port Pricing Strategies

Automated pricing systems leverage AI to adjust prices dynamically based on operational costs and demand. Customized strategies enhance customer retention, while

competitive pricing makes tech-driven services more accessible. Premium pricing for high-value services reflects superior quality. Overall, RAISA boosts ports' competitiveness and revenue by optimizing pricing efficiency and flexibility.

Impact on Port Distribution and Logistics

- Predictive Analytics for Cargo Flow Management: AI-driven systems analyze historical and real-time data to forecast shipment volumes, vessel arrivals, and potential disruptions. This enables proactive resource planning, optimized inventory management, and reduced turnaround times.
- Dynamic Resource Allocation Across Channels: Smart distribution systems automatically assign cargo and vessels to optimal terminals, berths, and transport routes based on capacity, urgency, and cost-efficiency. This minimizes congestion and maximizes throughput.
- AI-Powered Digital Assistants for Operational Coordination: Integrated voice and chat-based AI platforms (e.g., port-specific digital assistants) provide stakeholders with instant updates on cargo status, documentation, and logistics coordination. This streamlines communication and reduces administrative delays.
- Automated Intermodal Distribution Coordination: RAISA synchronizes sea, rail, and road transport by dynamically adjusting schedules and routes. This ensures seamless cargo handovers, reduces idle time, and enhances supply chain fluidity.
- Demand-Responsive Storage and Retrieval: AI algorithms predict short-term storage needs and automate container positioning within yards, optimizing space utilization and accelerating retrieval processes.

User Satisfaction and RAISA Usage

Understanding user acceptance of AI technologies in service delivery is crucial, and the RAISA user satisfaction model offers significant insights. It combines Cognitive Dissonance Theory, which explains users' discomfort when AI conflicts with their beliefs, leading to resistance (Festinger, 1962), and Cognitive Appraisal Theory, which focuses on how users evaluate AI based on perceived benefits and risks (Lazarus, 1991). Positive evaluations enhance satisfaction, while negative ones can impede acceptance. Together, these theories illuminate factors influencing AI adoption.

The acceptance process for RAISA technologies by port customers involves multiple stages, starting with awareness of potential benefits and moving to evaluation of pros and cons. Supporting factors include operational convenience through automation, enhanced efficiency via AI-driven optimization, and service customization with tailored data analytics. However, opposing factors like fear of operational disruption and loss of professional interaction may hinder acceptance, as customers value flexibility and traditional relationships in the maritime sector.

These supporting and opposing factors interact dynamically. A customer might highly value the efficiency gains from an automated booking system while simultaneously worrying about the depersonalization of service and the potential for errors in a fully automated workflow.

This complex interplay directly dictates customer satisfaction. If the tangible benefits of RAISA—such as predictability, speed, and transparency—consistently materialize,

customer acceptance and loyalty are likely to grow. Conversely, if concerns about inflexibility and impersonal service dominate the experience, satisfaction will be negatively impacted, potentially hindering the long-term adoption of these technologies (Wu, Sorokina, & Putra, 2023, pp. 1230-1243).

Leveraging AI and Automation for Environmental Sustainability in Port Operations

The environmental sustainability benefits of employing AI-driven systems and Automated Guided Vehicles (AGVs) in container terminals are significant. This approach quantifies the potential reductions in emissions and energy consumption achieved through optimized vehicle routing and automated shoreside operations. AI has the capacity to facilitate synergistic actions within an automated port environment, leading to substantial improvements in eco-efficiency (Tsolakis, Zissis, Papaefthimiou, & Korfiatis, 2022, p. 4530).

Conclusion

This study investigates the impact of Robotics, Artificial Intelligence, and Service Automation (RAISA) technologies in the port and maritime logistics sector. Key findings reveal that RAISA enhances operational efficiency through optimized vessel traffic management and automated container handling, reducing waiting times and costs. Its predictive analytics capabilities improve risk management, while economic advantages arise from customized pricing and reduced operational costs. Additionally, RAISA supports environmental sustainability by minimizing energy consumption and emissions. However, successful implementation also hinges on human factors, including employee acceptance and customer satisfaction. The transition to automated systems, though requiring significant investment, offers long-term benefits. This research underscores that strategic RAISA adoption is essential for ports to thrive amid market demands and environmental challenges.

References

Agah, A., Cabibihan, J. J., Howard, A., Salichs, M. A., & He, H. (2016). Social Robotics. Proceedings of the 8th International Conference, ICSR 2016, Kansas City, MO, USA, November 1-3, 2016. (Vol. 9979). Springer.

Blokus, A., & Dziula, P. (2019). Safety analysis of interdependent critical infrastructure networks. TransNav, International Journal on Marine Navigation and Safety od Sea Transportation , 13 (4), pp. 781-787.

Cepowski, T., & Chorab, P. (2021). Determination of design formulas for container ships at the preliminary design stage using artificial neural network and multiple nonlinear regression. Ocean Engineering (238), p. 109727.

Chen, Y., & Hu, H. (2013). Internet of intelligent things and robot as a service. Simulation Modelling Practice and Theory , 34, pp. 159-171.

Festinger, L. (1962). Cognitive dissonance. Scientific American , 207 (4), pp. 93-106.

Foster, M. N., & Rhoden, S. L. (2020). The integration of automation and artificial intelligence into the logistics sector: A Caribbean perspective. Worldwide Hospitality and Tourism Themes , 12 (1), pp. 56-68.

Ghazaleh, M. A. (2023). Smartening up ports digitalization with artificial intelligence (AI): A study of artificial intelligence business drivers of smart port digitalization. Management and Economics Review , 8 (1), pp. 78-97.

Huang, M. H., & Rust, R. T. (2018). Artificial intelligence in service. Journal of service research , 21 (2), pp. 155-172.

Huang, X., Wang, J., Xu, Y., Zhu, Y., Tang, T., & Xu, F. (2018). Dynamic modeling and analysis of wave compensation system based on floating crane in smart port. In 2018 International Symposium in Sensing and Instrumentation in IoT Era (ISSI) (pp. 1-5). IEEE.

Huang, Y., Li, Y., Zhang, Z., & Liu, R. W. (2020). GPU-accelerated compression and visualization of large-scale vessel trajectories in maritime IoT industries. IEEE Internet of Things Journal , 7 (11), pp. 10794-10812.

International Organization for Standardization. (2012). ISO 8373:2012(en) Robots and robotic devices — Vocabulary. Retrieved from https://www.iso.org/obp/ui/#iso:std:iso:8373:ed-2:v1:en

Ivanov, S. H., & Webster, C. (2017). Adoption of robots, artificial intelligence and service automation by travel, tourism and hospitality companies–a cost-benefit analysis. International Scientific Conference "Contemporary tourism – traditions and innovations. 19-21 October 2017. Sofia University.

Kanellos, F. D., Volanis, E. S., & Hatziargyriou, N. D. (2017). Power management method for large ports with multi-agent systems. IEEE Transactions on Smart Grid , 10 (2), pp. 1259-1268.

Korostin, O. (2025). Development Of Ai Solution For Port Operations Automation And Cargo Flow Management. Молодий вчений .

Kosiek, J., Kaizer, A., Salomon, A., & Sacharko, A. (2021). Analysis of modern port technologies based on literature review. TransNav: International Journal on Marine Navigation and Safety of Sea Transportation , 15 (3), pp. 667-674.

Kuo, S. Y., Huang, X. R., & Chen, L. B. (2022). Smart ports: Sustainable smart business port operation schemes based on the Artificial Intelligence of Things and blockchain technologies. IEEE Potentials , 41 (6), pp. 32-37.

Law, R., Buhalis, D., & Cobanoglu, C. (2014). Progress on Information and Communication Technologies in Hospitality and Tourism. International Journal of Contemporary Hospitality Management , 26, pp. 727-750.

Lazarus, R. S. (1991). Progress on a cognitive-motivational-relational theory of emotion. American psychologist , 46 (8), p. 819.

Lestari, N. S. (2022, October). Impact of robots, artificial intelligence, service Automation (RAISA) acceptance, self-efficacy, and relationship quality on job performance. (IEEE, Ed.) In 2022 4th International Conference on Cybernetics and Intelligent System (ICORIS) , pp. 1-6.

Mellit, A., & Kalogirou, S. A. (2008). Artificial Intelligence Techniques for Photovoltaic Applications: A Review. Progress in Energy and Combustion Science , 34, pp. 574-632.

Meziane, M. T., & Bouguetaia, S. (2023). Impact of financial technology on Algerian bank performance., 7(4), . Journal of Innovations and Sustainability , 7 (4), pp. 07-07.

Poole, D. L., & Mackworth, A. K. (2010). Artificial Intelligence: Foundations of Computational Agents. Cambridge University Press.

Prentice, C., Weaven, S., & Wong, I. K. (2020). Linking AI Quality Performance and Customer Engagement: The Moderating Effect of AI Preference. International Journal of Hospitality Management , 90, p. 102629.

Sostero, M. (2020). Automation and robots in services: review of data and taxonomy y, JRC Working Papers Series on Labour, Education and Technology, No. 2020/14. Seville: European Commission, Joint Research Centre (JRC).

Stuart-Hill, T. (Vienna). Big Bang Theory: 360 Overview of Automation Technology Impacts in Travel, Tourism &Hospitality. innovation description the evolution of hospitality .

Tsolakis, N., Zissis, D., Papaefthimiou, S., & Korfiatis, N. (2022). Towards AI driven environmental sustainability: an application of automated logistics in container port terminals. International Journal of Production Research , 60 (14), pp. 4508-4528.

Van Thiel, D., & Van Raaij, W. F. (2019). Artificial intelligence credit risk prediction: An empirical study of analytical artificial intelligence tools for credit risk prediction in a digital era. Journal of Risk Management in Financial Institutions , 12 (3), pp. 268-286.

Wu, F., Sorokina, N., & Putra, E. D. (2023). Customers satisfaction on robots, artificial intelligence and service automation (RAISA) in the Hotel Industry: A comprehensive review. Open Journal of Business and Management , 3, pp. 1227-1247.

Yang, Y., & et al., .. (2018). Internet of things for smart ports: Technologies and challenges. IEEE Instrumentation & Measurement Magazine , 21 (1), pp. 34-43.

Yassin, ,. E., Gharieb, ,. A., & Saad, ,. H. (2022). Robots, artificial intelligence, and service automation (RAISA) technologies in the Egyptian hotel sector: A current situation assessment. International Journal of Heritage, Tourism and Hospitality , 16 (1), pp. 51-60.

Yuan, S., Skinner, B. T., Huang, S., Liu, D. K., Dissanayake, G., Lau, H., et al. (2010). Mathematical modelling of container transfers for a fleet of autonomous straddle carriers. In 2010 IEEE International Conference on Robotics and Automation (pp. 1261-1266). IEEE.

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